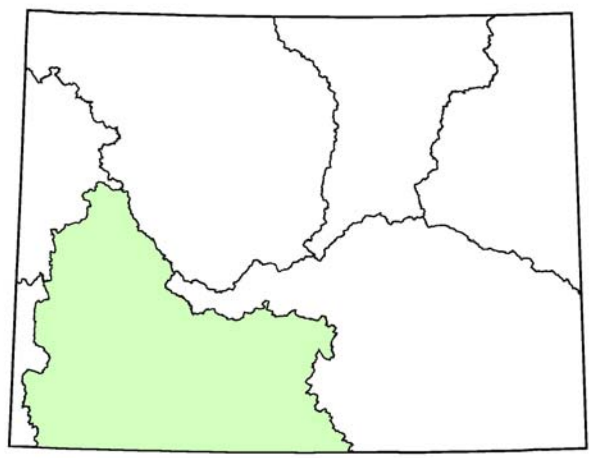
Green River Basin Plan

December 2010



Prepared for:

Wyoming Water Development Commission
Basin Planning Program

Prepared by:

WWC Engineering
AECOM
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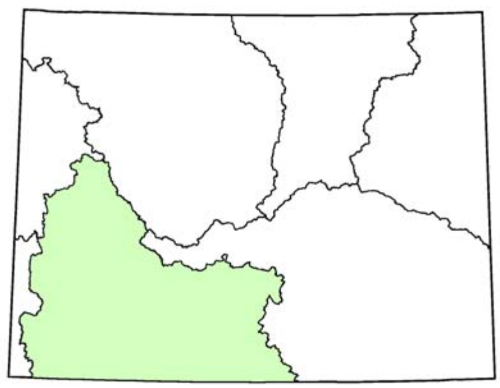

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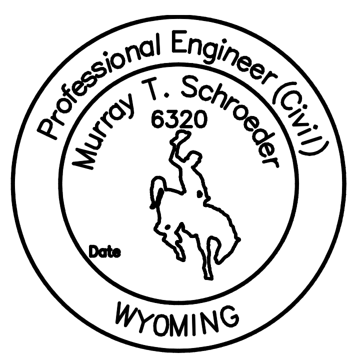


I, Murray T. Schroeder, a Wyoming registered Professional Engineer, certify that this report was prepared by me or under my direct supervision. The original signature and stamp are available at the Water Development Office.

Table of Contents

1.0 INTRODUCTION

1.1 OVERVIEW

This 2010 Green River Basin Plan presents a basinwide perspective on water resources, updated from the 2001 Green River Basin Plan including information on:

- The **Setting** chapter presents basic physical information about the Green River Basin, current economic and social conditions, and an outline of the institutional constraints on water use.
- The **Resources** chapter characterizes the Green River Basin's total water supply, including information on where the resources are located and their quality.
- The **Use** chapter quantifies how the Green River Basin is currently using its water resources in both the depleting and non-depleting water use sectors.
- The **Projections** chapter provides estimates of the future water needs of the Green River Basin, for the depleting and non-depleting water use sectors.
- The **Availability** chapter presents estimates of the amounts and locations of unused water resources that are available to meet needs. Unused water resources are those that are physically and legally available over and above existing uses.
- Finally, the **Strategies and Recommendations** chapter presents general and specific suggestions for basin stakeholders to consider as they attempt to resolve water issues.

In addition to presenting information on water resources of the State, this document covers two other important subjects:

- A **Web-based Presentation Tool** is described in Chapter 2. This tool makes the results of this Plan available online and provides a structure that will promote efficient future planning updates.
- **Project Funding** is presented in Chapter 9. This chapter outlines opportunities for project proponents to obtain state and federal funding assistance.

This report does not include all-inclusive and explicit lists of references. Instead, all references to supporting reports, documents, maps, and personal communications are maintained in the Technical Memoranda that were prepared during the current planning process. Should the reader desire to review a complete list of references for the information presented in this report they are referred to the full Technical Memoranda.

1.2 NEED FOR PLANNING

The Wyoming water planning process is founded on the Prior Appropriation Doctrine and the principle that the State of Wyoming should manage its water resources "for the benefit of the citizens of the state." The Wyoming Water Development Commission (WWDC) was created by the 1979 Wyoming Legislature and is charged with responsibility for "…the planning, selection, financing, construction, acquisition, and operation of projects and facilities for the conservation, storage, distribution, and use of water, necessary in the public interest to develop and preserve Wyoming's water and related land resources."

In order to preserve Wyoming's compact allocation of water for the benefit of its citizens and insurance against future water shortages, it is necessary to gather good quality, current, comprehensive data that can serve as the foundation for water projects.

2.0 WEB TOOL

This 2010 Green River Basin Plan is available to view and download at http://waterplan.state.wy.us/plan/green-plan.html. In addition to the executive summary and final report, technical memoranda, hydrologic models, and related GIS data are also available for download.

2.1 SEARCHING

The *Water Search Engine* (http://waterplan.state.wy.us/sites.html) may be accessed from the Wyoming State Water Plan website. This customized Google search engine allows users to search the State Water Plan and the WWDC websites for information related to river basin planning, WWDC reports, and other documents and data housed by the WWDO and WRDS.

2.2 DATABASE TABLES

Data presented in the *2007 Statewide Framework Water Plan* (SFWP) represent values compiled from the seven individual River Basin Plans created during the first round of basin planning (1999-2006). Twenty-one data tables from the SFWP were revised with new values derived from links to the values from the SFWP, are available at http://waterplan.state.wy.us/plan/statewide/tables/tables.html. The values in these updated tables represent the most recent data available at the time of publication. Those values that were revised after the completion of the SFWP are identified in red and the date of the update is given.

2.3 MAPS

High resolution PDFs are available for all of the maps generated during the *2010 Green River Basin Plan*. Viewing or printing the PDFs requires the Adobe Acrobat PDF viewer, which is available for free download at www.adobe.com/products/acrobat/readstep2.html.

3.0 SETTING

This chapter presents basic physical information about the Green River Basin, current economic and social conditions, and a summary of the legal and institutional constraints on water use.

3.1 PHYSICAL SETTING

The Green River Basin (Basin) includes lands in Wyoming, Colorado, and Utah that drain to the Green River. In Wyoming, the Basin is bordered on the east by the Continental Divide formed by the Wind River Range in the north and northeast, the Great Divide Basin centrally, and the Sierra Madre Range in the southeast. The Wyoming portion of the Green River Basin is bordered on the south by the Wyoming-Colorado and Wyoming-Utah state lines. The Basin's western border is defined by the Tunp Range[1], which forms the division between the Green and Bear River Basins, and the Wyoming Range, which separates the Green from the Greys River Basin. The far northwest of the Basin is bounded by the Gros Ventre Range.

Counties with significant areas in Wyoming's Green River Basin are Sweetwater, Sublette, Carbon, Lincoln, and Uinta; small areas of Fremont and Teton Counties are also located within the Basin, giving the Wyoming portion of the Basin an area slightly larger than the State of West Virginia. Figure 3-1 is a river basin planning map of Wyoming.

3.1.1 Land Area and Ownership

The land area of Wyoming's Green River Basin is approximately 21,047 square miles and comprises 21.3 percent of the state. Of that, 69 percent is federally owned, 27 percent privately owned, 4 percent is owned by the state and local government, and less than 1 percent is water surface (*Equality State Almanac, 2007)*. Table 3-1 presents Green River Basin land area by county and Figure 3-2 shows the distribution of State, Federal and Private Lands across the Basin.

3.1.2 Physiography

<u>*Topography*</u>

The Basin generally slopes to the south, and the majority of the Basin has an elevation in the range of 6,000 to 7,000 feet above sea level. This area is characterized by the buttes, mesas, and badlands associated with high, arid desert plains. Mountainous peaks that form the majority of the Basin border frequently exceed 10,000 feet in

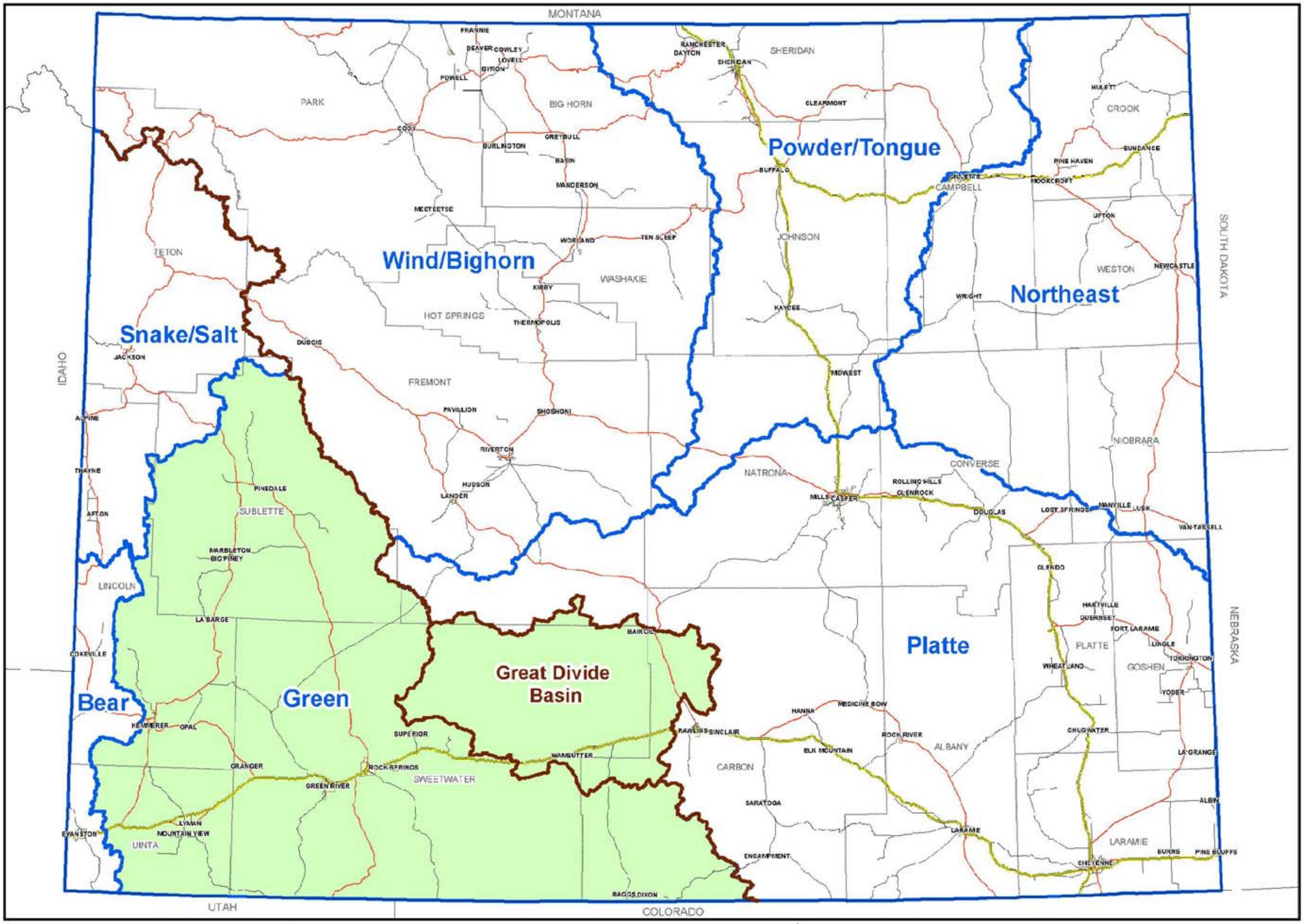
[1] "More mountains lie to the north that are not considered part of the Tunp Range, but are effectively contiguous. This includes Commissary Ridge to the northeast. The Tunp Mountains are in the Bridger National Forest."

elevation in the northern and northeastern reaches of the Basin, and 9,000 feet in the southern reaches of Wasatch National Forest. The highest point in the Basin (Gannett Peak, elevation 13,804) is also the highest point in the state, and the lowest point (elevation 6,040) occurs along the Green River where it passes into Utah at Flaming Gorge Reservoir.

Table 3-1 Land Area by County

	Area of County (Acres)	Area of Green River Basin in County (Acres)	Area of Great Divide Basin in County (Acres)
Teton	2,706,987	6,890	0
Sublette	3,161,111	2,846,065	0
Lincoln	2,621,447	1,243,945	0
Uinta	1,338,374	1,023,433	0
Sweetwater	6,716,917	4,824,077	1,870,281
Carbon	5,096,770	977,672	551,168
Fremont	5,932,823	53,536	72,725
Total Acres	27,574,430	10,975,618	2,494,174
Total Square Miles	43,085	17,149	3,897
Total Area of Green and Great Divide Basins (square miles)			21,047

Source : Areas in this table were determined from GIS shape file coverages available from WYGISC.

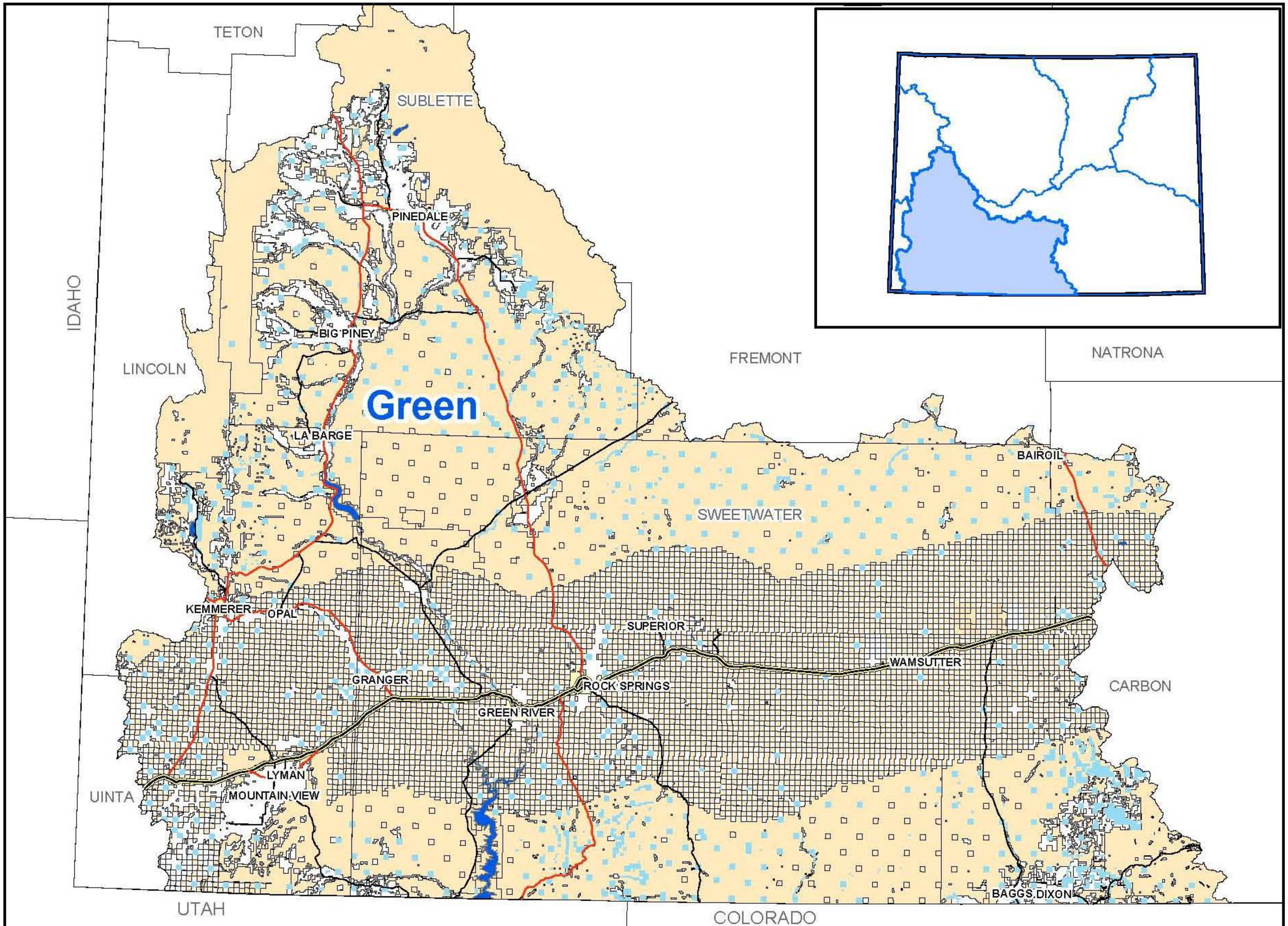


LEGEND

River Basin Planning Area — Continental Divide

Note: The Great Divide Basin is a closed basin included within the Green River Basin Planning Area.

Figure 3-1
River Basin Planning Area Map



LEGEND

Private State Federal

Figure 3-2
Green River Basin Land Ownership

Drainage System

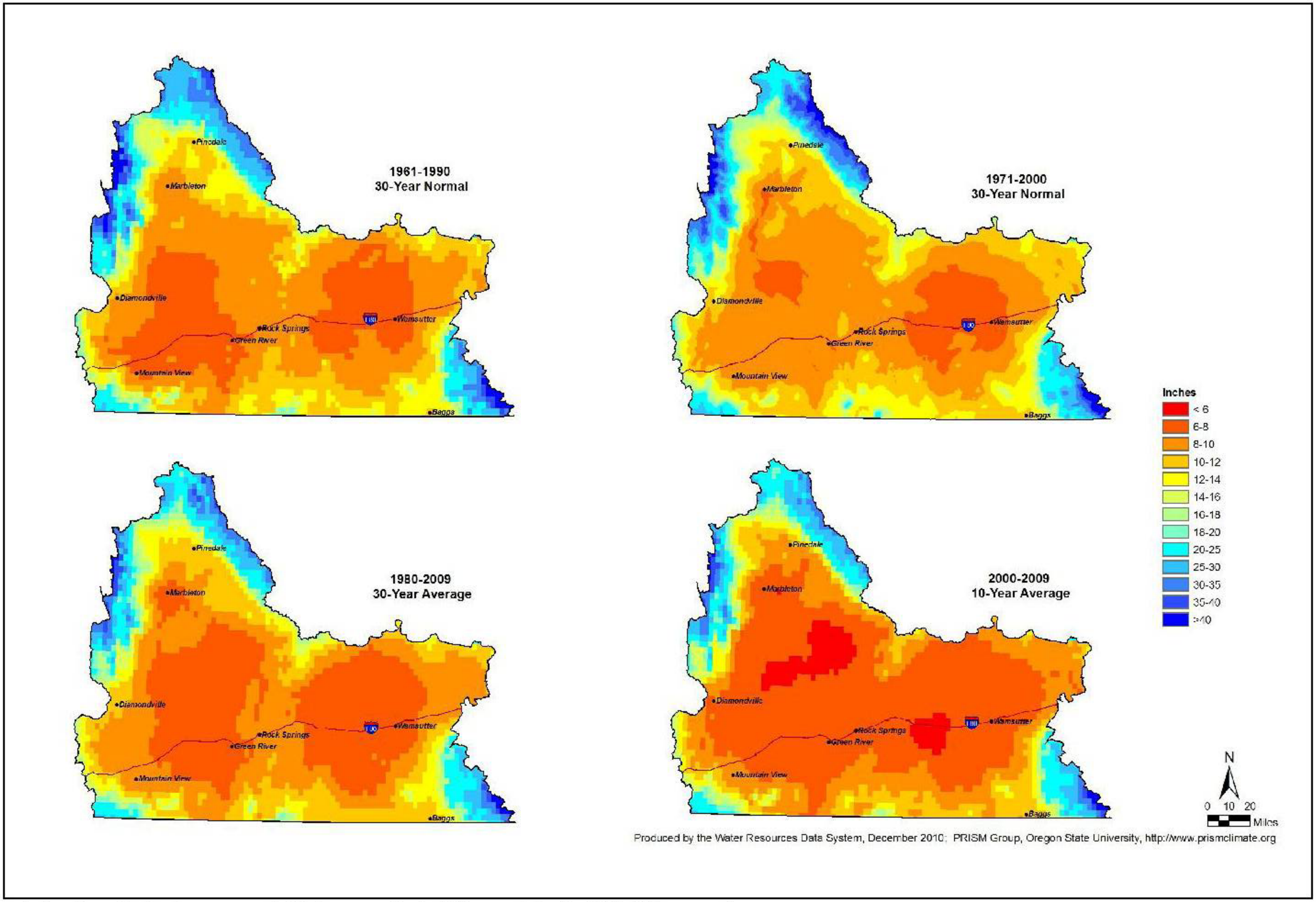
The Green River Basin's rivers and streams drain to the Green River, the largest tributary of the Colorado River. For purposes of this plan the Green River Basin includes the Great Divide Basin, a closed basin that does not contribute runoff to the Green River. The Great Divide Basin drains 4 percent of Wyoming. The Little Snake Basin, which flows into the Yampa River in Colorado which in turn is tributary to the Green River, is also included in the Green River Basin for this plan; these three drainage basins together are sometimes referred to as the Greater Green River Basin and here shall simply be referred to as the Green River Basin or the Basin.

3.1.3 Climate

Water gathered into rivers and streams originates as precipitation. Water that "makes it" to the stream is that which is not evaporated from the surface by solar and wind energy; not intercepted by plants whose capacity and need for water is influenced by solar radiation and relative humidity; and not taken up by the soil moisture reservoir, whose capacity is determined by antecedent precipitation and temperatures. In a snowmelt-driven system, timing and intensity of runoff is related to both accumulated precipitation as snow, and springtime temperatures, radiation, and wind. Hence, water availability is governed by climate.

Climate throughout the Basin varies as a function of elevation, latitude and orographic effects, but most of the Basin follows the pattern of a high desert region. Higher precipitation and lower temperatures generally accompany higher elevations. On average, the Basin receives between 10 to 15 inches of precipitation annually with less than 13% of the Basin receiving more than 20 inches. The southwestern slopes of the Wind River Range, the eastern slopes of the Wyoming Range, and the western slopes of the Sierra Madres receive the most precipitation in the Basin. Lower elevations receiving the most precipitation are located in the upper portion of the Basin in the vicinity of Pinedale. The mountain areas generally have an average annual precipitation from 21 to 59 inches, most of which falls as snow. On average, the Basin receives the most precipitation in April and May and the least in December and February. The higher elevations receive the majority of their precipitation in winter months (October – March) when the lower elevations in the middle of the Basin are at their driest. While long, mild - intensity rainfall events do occur in the Basin, the majority of the rainfall occurs in short, intense storms. Figure 3-3 presents a comparison of precipitation data for different time periods, including the last 10 years of dry records. Figure 3-4 shows how precipitation distribution changes by month.

The warmest average annual temperatures tend to occur in the Flaming Gorge region with the coldest occurring in the upper portions of the Basin, between the Wyoming and Wind River Ranges. Figure 3-5 shows annual average temperatures in the Green River Basin.



The term "normal" refers to averages calculated across a standard 30-year period, either 1961-1990 or 1971-2000. Such 30-year normals are used in climatic and hydrological analyses, and the normal values presented here were calculated by the NOAA National Climatic Data Center. The term "averages" refers to values calculated by WRDS across a non-standard time period (1980-2009 or 2000-2009).

Figure 3-3
Annual Precipitation Comparisons

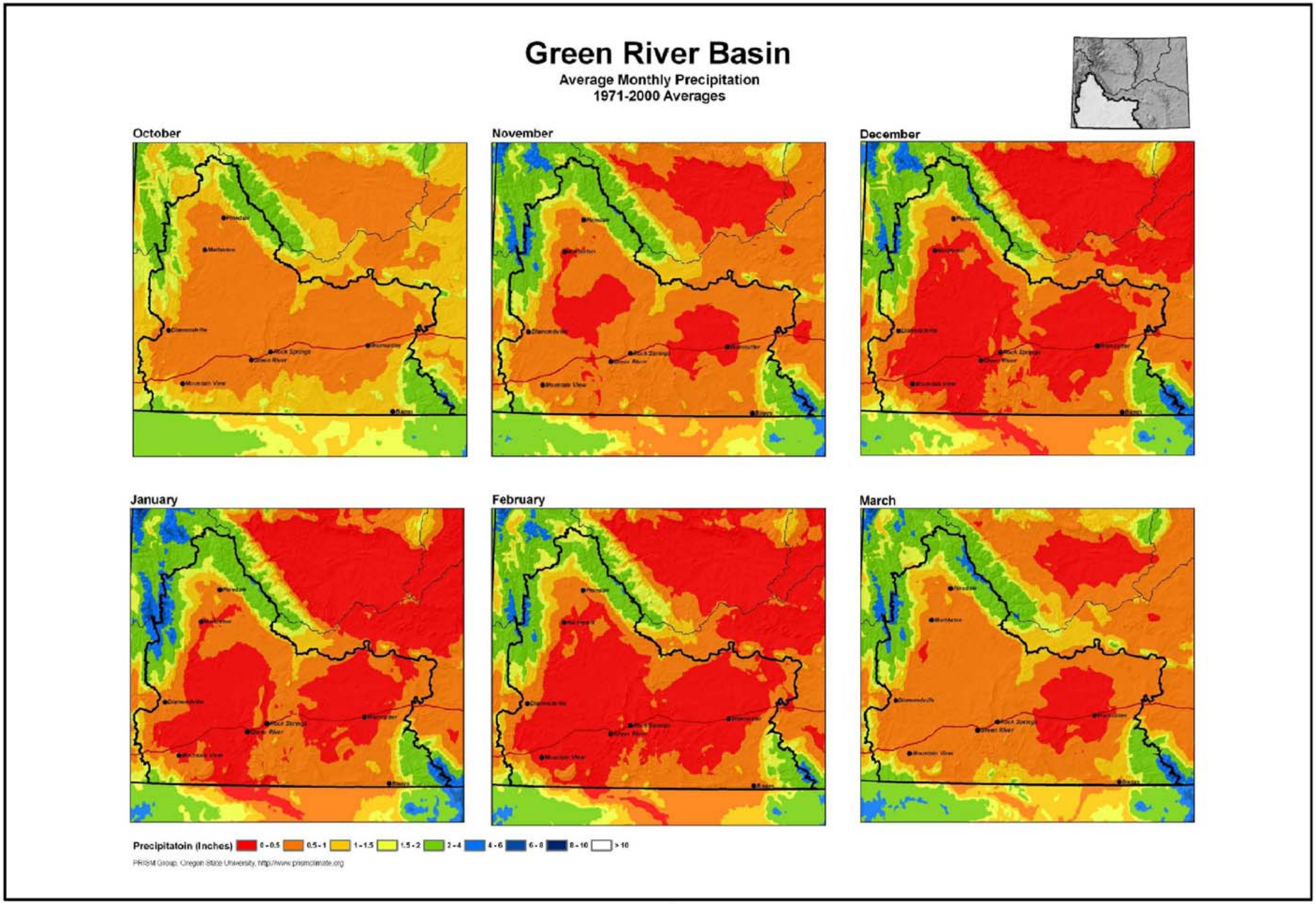


Figure 3-4
Average Monthly Precipitation, 1971-2000 Averages

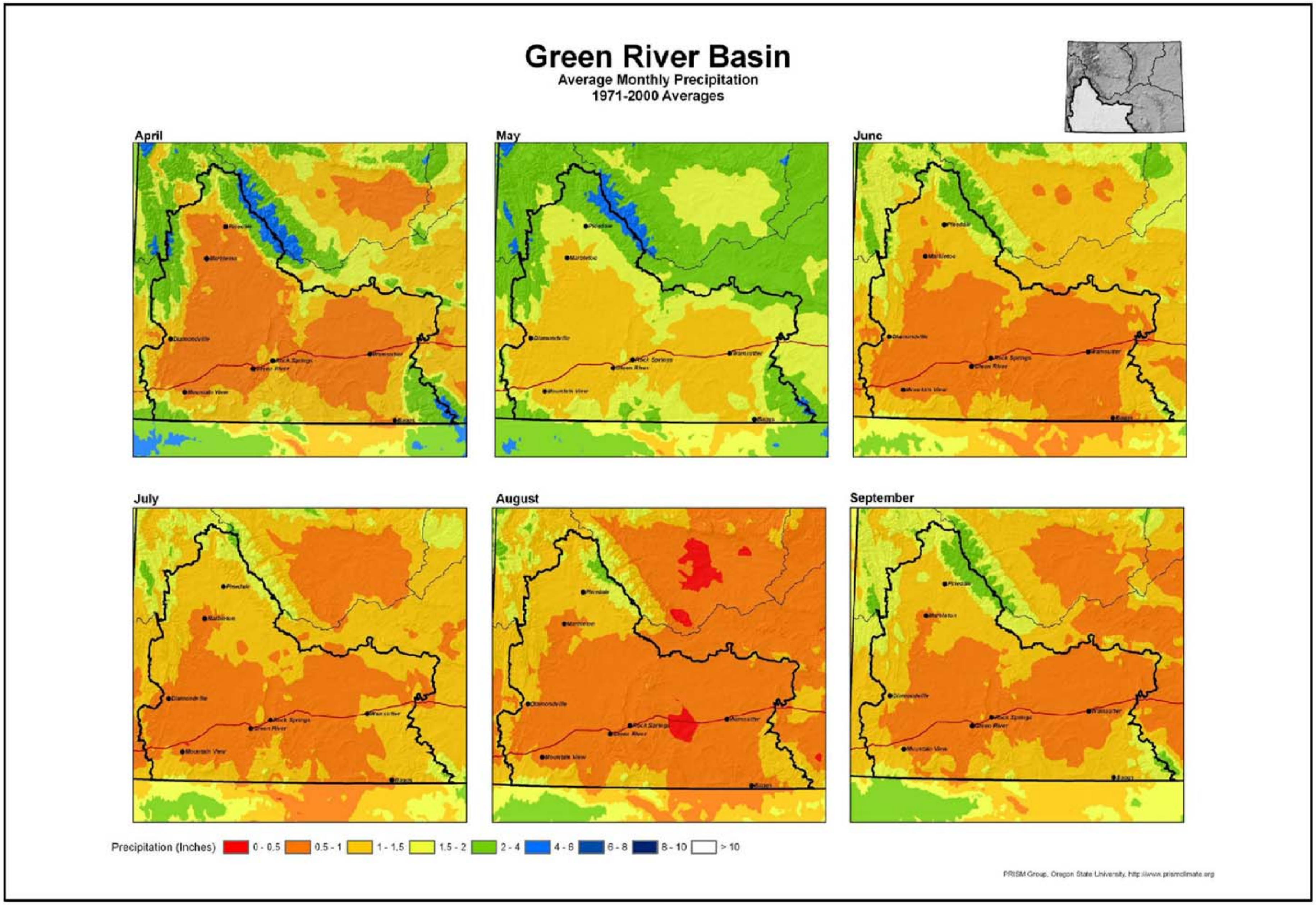
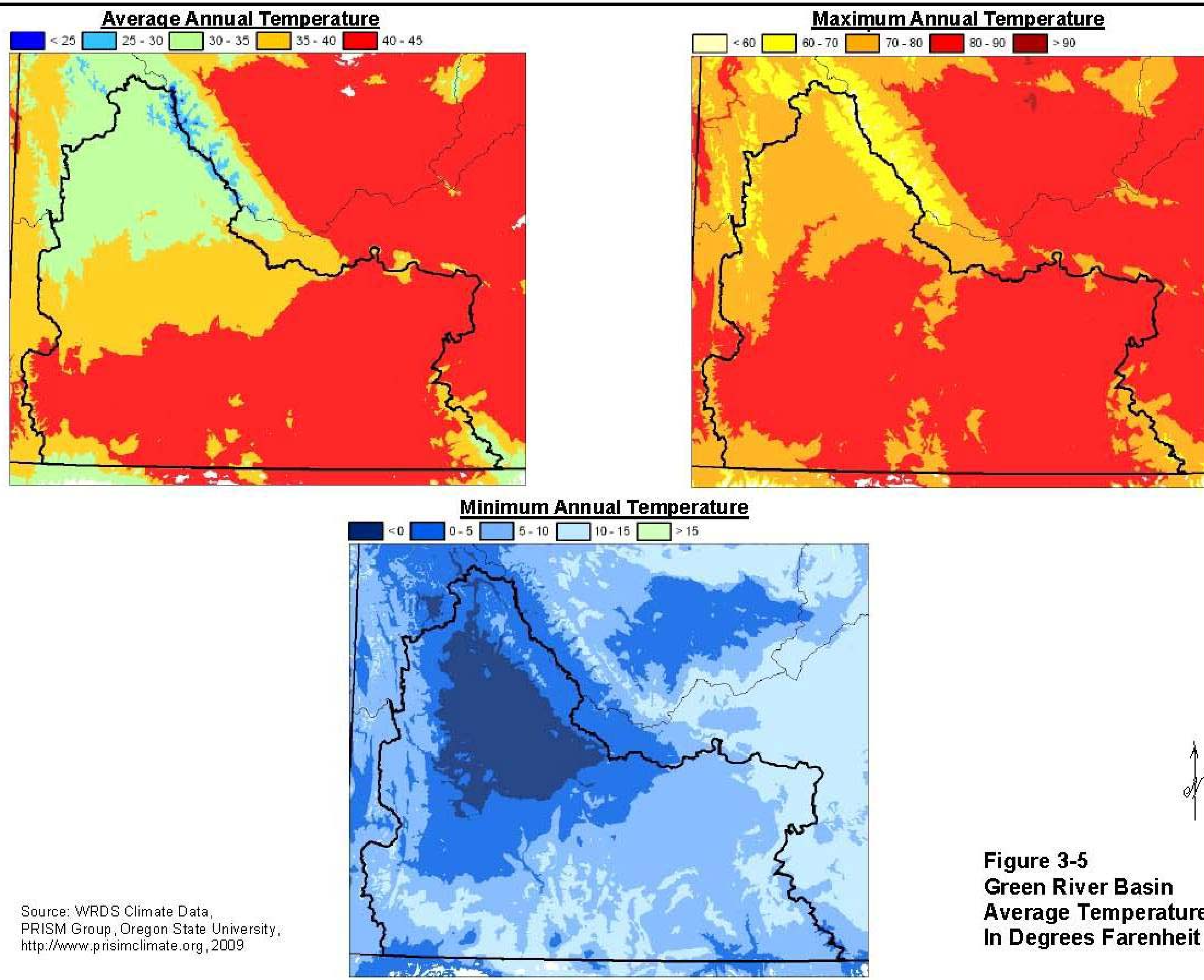


Figure 3-4 Cont
Average Monthly Precipitation, 1971-2000 Averages



Source: WRDS Climate Data,
PRISM Group, Oregon State University,
http://www.prisimclimate.org, 2009

Figure 3-5
Green River Basin
Average Temperatures
In Degrees Farenheit

The Green River Basin is characterized by a relatively short growing season due to high elevations, a short frost-free period in the spring, summer, and fall, and sporadic distribution of precipitation throughout the year. Climate data presented herein comes from PRISM (Parameter-elevation Regressions on Independent Slopes Model), a spatially gridded average monthly and annual precipitation for the 30 year period 1971-2000. PRISM is a unique knowledge-based system that uses point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters. This way of calculating averages across the entire Basin is more accurate than averaging individual stations because it leaves fewer gaps on the landscape and in time.

3.2 SOCIOECONOMIC SETTING

3.2.1 Historic Population Growth

Most demographic data are compiled on the basis of political units such as states, cities, and counties, and most economic data are reported on the county, state, or national level. Because much of the following data is not reported or maintained on a river basin basis, approximations were calculated using the five counties that make up the Green River Basin: Carbon, Lincoln, Sublette, Sweetwater, and Uinta (excluding Fremont and Teton counties which make up a small percentage of the Basin and whose portions of the Basin are largely unpopulated). County rural population data was adjusted by the percentage of the county that lies in the Green River Basin. Cities and towns were included if they are within the boundary of the Green River planning area.

The population of the Green River Basin was estimated at 34,325 in 1950 and grew to about 60,283 in 2005 according to the Wyoming Department of Administration and Information, Economic Analysis Division (WDAI) based on U.S. Census Bureau estimates of reported populations of incorporated cities and towns plus estimated rural population from GIS data. GIS-based census data were only available for 2000 and 2005 from WDAI. Almost two-thirds of the Basin's current population (63%) resides in Sweetwater County; Lincoln, Sublette, and Uinta Counties each have 11 to 13 percent of the Basin's population, while only 2 percent resides in Carbon County. The relatively large population concentration in Sweetwater County is attributable to the fact that it contains the two largest communities in the Basin, Rock Springs and Green River. These two cities, with a combined population of about 30,559, account for 51 percent of the Basin's current population.

From 1970 to 1980, the population of the Basin grew from 29,574 to 60,255, an increase of 30,681 persons. That increase came about as a result of rapid development of energy and mineral resources in the Basin and the associated influx of workers. Since then, barring a minor decrease during the 1980-1990 Energy Bust, the Green River Basin's population has been increasing fairly steadily. Rapid changes in population are often associated with or tied to booms and busts in the energy and mineral sectors. Table 3-2 shows population changes by county.

Table 3-2 Green River Basin Population

County/Community	Population 2000	Population 2005
Carbon Co.	**1,075**	**1,106**
Baggs	348	354
Dixon	79	81
Rural	648	671
Lincoln Co.	**7,300**	**7,781**
Diamondville	716	695
Kemmerer	2,651	2,560
La Barge	431	421
Opal	102	99
Rural	3,400	4,006
Sublette Co.	**5,594**	**6,541**
Big Piney	408	455
Marbleton	720	811
Pinedale	1,402	1,658
Rural	3,064	3,617
Sweetwater Co.	**37,613**	**38,015**
Bairoil	97	96
Granger	146	146
Green River	11,808	11,787
Rock Springs	18,649	18,772
Superior	244	239
Wamsutter	261	265
Rural	6,408	6,710
Uinta Co.	**6,685**	**6,840**
Lyman	1,938	1,937
Mountain View	1,153	1,163
Rural	3,594	3,740
Total[1]	**58,267**	**60,283**

Source: WWC Engineering, Tech. Memo, 2009 (M)

[1] This is the five county area within the Green River Basin total, neglecting Teton and Fremont Counties.

3.2.2 Aging Populations, Employment, and Labor Force Participants

Wyoming's population is older than the national population; the median age in Wyoming is 38.4 years while the national median age is 36.6 years. Wyoming has progressed from one of the youngest states to one of the oldest states. This increasing proportion of older residents is likely due to three factors: the aging of the large baby boom generation as seen across the U.S., the migration of retirees into Wyoming seeking

Wyoming's low cost of living, and the migration of young people out of Wyoming looking for employment opportunities. Table 3-3 shows the age group percentages of the population of the 5 counties that encompassed the populated area of the Green River Basin in 2005. It is assumed that populations in the Green River Basin will age in a similar manner to the State of Wyoming populations.

Employment figures and data are not reported or maintained on a river basin basis. To approximate the employment situation in the Green River Basin, data from the five counties that largely comprise the Green River Basin are presented in Table 3-4. The county data were adjusted by the percentage of the county that lies in the Green River Basin Planning area.

In 2005 the annual average wage for the five-county area making up the Green River Basin was about $34,064. Table 3-4 shows the 2005-five county employed labor force, the county average wage and the county total earnings. These numbers, made up of the five-county totals, are not technically accurate for the Green River Basin hydrologic planning area but are indicative of the employment and earnings situation in the Green River Basin. Figure 3-6 shows employment demographics for the five county areas that make up the Green River Basin. Due to rounding, some of the sectors are shown as 0% in Figure 3-6 when in fact they do have a small level of employment.

3.2.3 Key Economic and Water Use Sectors

Agriculture, primarily irrigation, is by far the largest water consumer in the Basin. The energy and mineral sectors have historically added volatility to the economy, but they have also provided high-paying jobs and often require a large amount of water. While municipal water consumption is a small percentage of overall water use in the Basin, cities and towns have unique requirements that demand reliability. Travel, tourism and recreation contribute to the Green River Basin's economy and water plays an important, but somewhat different, role in this sector. Environmental water use is notable and indirectly affects the economy. Finally, there is an ongoing effort to attract new business and manufacturing interests to the Basin, which in the long run may increase the economic base and create new demand for water supplies. Each of the water demand sectors is integral to economic, demographic, and water demand projections for the Green River Basin.

Table 3-3 - 2005 Aging Population of the Green River Basin Five-County Area

Age Group	County					Total	Percent
Years	Carbon	Lincoln	Sublette	Sweetwater	Uinta		
Less than 5	847	981	347	2,678	1,468	**6,321**	6.6%
5 to 14	1,650	2,175	814	4,961	2,976	**12,576**	13.1%
15 to 19	979	1,279	489	3,092	1,694	**7,533**	7.8%
20 to 24	1,003	1,259	460	2,791	1,685	**7,198**	7.5%
25 to 34	1,658	1,759	864	4,619	2,235	**11,135**	11.6%
35 to 44	2,185	1,956	981	5,213	2,621	**12,956**	13.5%
45 to 54	2,831	2,727	1,277	6,994	3,626	**17,455**	18.2%
55 to 64	2,128	1,858	935	4,495	2,083	**11,499**	12.0%
65 to 74	1,140	1,111	475	1,762	831	**5,319**	5.5%
75 +	910	894	284	1,370	720	**4,178**	4.3%
Total	**15,331**	**15,999**	**6,926**	**37,975**	**19,939**	**96,170**	**100%**

Source: Equality State Almanac 2007

Note: the county population estimates provided in this table do not reflect adjustments for cities and towns that lie outside the Green River Basin.

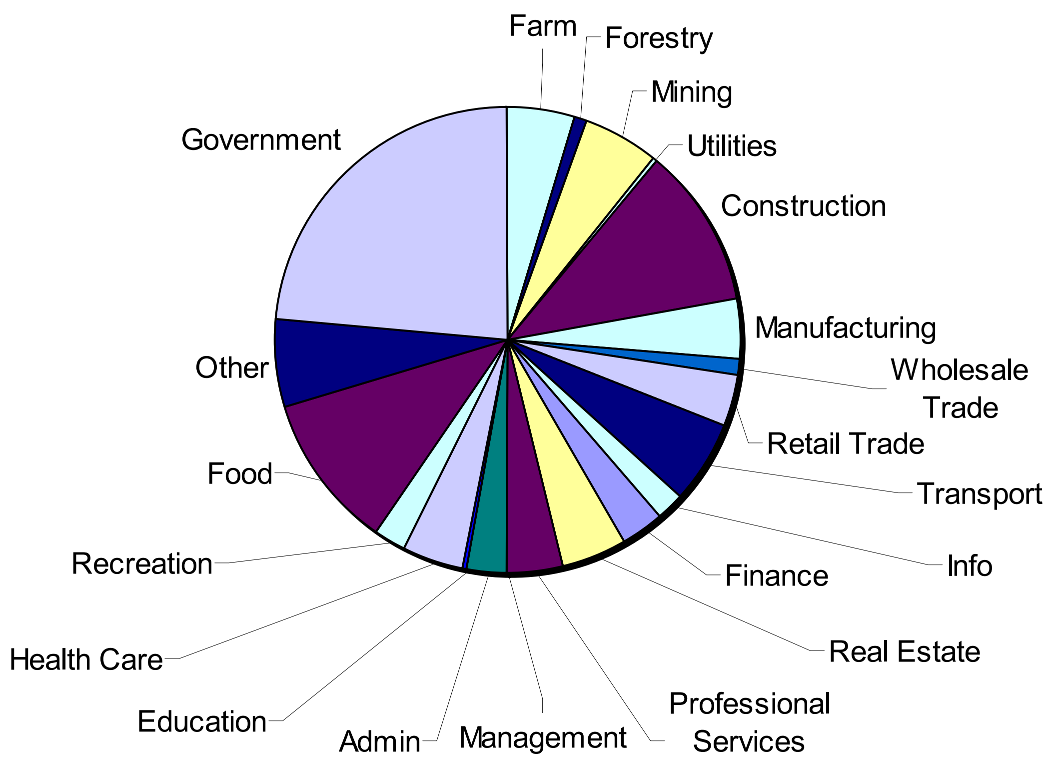
Table 3-4 - 2005 Labor Force Employed and Average Annual Wages for the Green River Basin Five-County Area

County	Labor Force Employed	Average Wage	Total Wages
Carbon	7,530	$28,903	$217,639,590
Lincoln	7,686	$31,524	$242,293,464
Sublette	5,109	$36,751	$187,760,859
Sweetwater	22,044	$42,088	$927,787,872
Uinta	10,599	$31,056	$329,162,544
GRB Total	**52,968**	**$35,958**	**$1,904,644,329**

Source: Equality State Almanac 2007

Note: The employed labor force estimates alone do not reflect adjustments for cities and towns that lie outside the Green River Basin.

Figure 3-6 Estimated Green River Basin Employment



Source: Equality State Almanac, 2007

Agriculture

Agriculture, specifically irrigation, consumptively uses more water than any other economic sector. In 2005 there were approximately 2,167 full and part time agricultural jobs in the five counties that make up the Green River Basin. In 2006-2007 there were 1,560 farms in the Green River Basin. For the same year the total value of agriculture in the Basin was $335.6 million. In 2007 there were 447,900 acres of irrigated agriculture, 28,816 acres of dry farm agriculture, and 4,951,421 acres of range land with a total assessed valuation of $30,273,944. Table 3-5 exhibits the types, amounts, and value of the different sectors of agriculture.

Livestock

Livestock production is the dominant agricultural practice in the Green River Basin and is the reason for the large amounts of alfalfa and grass hay grown in the area. Livestock numbers have declined since 2000 due to the severe drought the state has been experiencing. Drought conditions drive up feed prices and ranchers cannot afford to raise as many cattle and sheep. Livestock water consumption estimates are based on ten gallons of water per cow per day and four gallons of water per sheep per day. In 2005 the estimated livestock consumptive use was 3,200 acre-feet of water per year. For 2006-2007 the estimated value of livestock in the Green River Basin was $315.3 million.

Crops

The main crops in the Green River Basin consist of forage such as grass hay and alfalfa with very few small grain and cash crops. Typically the irrigated forage grasses are consumed by the producers' herds although some is sold locally or exported from the Basin. For 2006-2007 the estimated value of crops in the Green River Basin was $50.4 million.

Industrial

The industrial sector of the Green River Basin employed approximately 19,059 people in mining, utilities, construction, manufacturing, and transportation and warehousing in 2005. Total wages were $1,290,309,000. Natural gas is Wyoming's largest export product, and Sublette County is the top natural-gas producing county in the state. There is also significant coal mining in Lincoln and Sweetwater Counties. The Green River Basin is the location of three electric power generation facilities, one hydropower and two coal-fired. In 2006 the Green River Basin produced 13.9 million tons of coal, 15.9 million barrels of crude oil, 19 million tons of trona, and 1,451,245 thousand cubic feet (MCFs) of natural gas.

Table 3-5 - Acreage and Assessed Valuation of Agricultural Land in the Green River Basin

	Irrigated		Dry Farm		Range	
County	**Acres**	**Value**	**Acres**	**Value**	**Acres**	**Value**
Carbon	138,363	$4,312,565	10,059	$137,535	1,775,926	$4,045,465
Lincoln[1]	78,523	$4,343,625	18,757	$294,101	416,445	$1,606,876
Sublette	133,549	$2,968,810	0	0	412,525	$3,170,288
Sweetwater	23,121	$986,062	0	0	1,702,407	$3,365,557
Uinta[1]	74,344	$2,967,476	0	0	644,118	$2,075,584
Total	**447,900**	**$15,578,538**	**28,816**	**$431,636**	**4,951,421**	**$14,263,770**

Source: Equality State Almanac 2007

Note: The methods used to estimate irrigated acreage, as reported in the Equality State Almanac, are unknown to WWC Engineering. We acknowledge that the acreage in the above table is different than estimates presented elsewhere in this Plan.

[1] A large portion of Lincoln and Uinta County irrigated acreage is actually in the Bear River Basin.

Municipal and Domestic

Municipal and domestic water use is a relatively small but important part of overall water use. Census data for 2000 indicated that 64% of the population in the Green River Basin lived in urban areas. This urbanization trend is expected to continue with a greater percent living in urban areas served by municipal water resulting in a greater demand on municipal water.

Population in the Green River Basin increased 3.4% between 2000 and 2005, a trend that is expected to continue. This increase in population translates to increased water needs and use in both rural and urban sectors.

Recreation, Travel and Tourism

Water is an important component in recreation and tourism, providing opportunities for boating, fishing, hunting, camping, golfing, and skiing taking place on or near rivers, streams, lakes, and reservoirs of the Green River Basin. The top 15 outdoor recreation activities in the Basin are directly dependent on or related to water, Recreation employed 5,750 people in the Green River Basin with those people earning $121.5 million in 2007. A total of $550 million was spent on travel and tourism in the Basin in 2007, or about 20% of the total in Wyoming. Table 3-6 summarizes the economic impacts of travel and tourism in the Green River Basin.

The Green River Basin has several major reservoirs. Flaming Gorge Reservoir and Fontenelle Reservoir are important destinations for recreation although they are not strictly recreation reservoirs. Other major reservoirs such as Eden, Viva Naughton, Meeks Cabin, Willow and Big Sandy Reservoirs were constructed for flood control, irrigation, power generation, and/or municipal water supply and do not have recreation reserve pools. As a result, recreational use at these reservoirs usually peaks in July and then declines as water levels are drawn down to satisfy their permitted uses.

Table 3-6 - Economic Impacts of Travel by Green River Basin County, 2007

County	Travel Spending	Travel Spending Change 97-07	Earning	Employment	Employment Change 97-07
	$ Millions		$ Millions		
Carbon	159.6	8.50%	33.1	1,580	3.80%
Lincoln	62.4	7.30%	12.2	630	1.20%
Sublette	50.5	10.10%	17.2	510	3.30%
Sweetwater	176.5	7.90%	39.3	2,010	3.40%
Uinta	101.2	8.20%	19.7	1,020	2.60%
Total or Average	550.2	Avg=8.4%	121.5	5,750	Avg=2.9%
State Total	2,68.7	6.50%	675.9	30,330	1.60%
Percent of State Total	20%	n/a	18%	19%	n/a

Source: ERO Resources Corporation, Tech. Memo, 2009 (J)

Environmental

For the purposes of water demand forecasting, environmental water use includes only water used in efforts to enhance environmental conditions, such as improving or maintaining fish and wildlife habitats. Much of the environmentally beneficial water use within the state is a by-product of other uses, such as reservoirs, and not from water rights specifically directed at environmental protection. Wyoming's Instream Flow Law and the Seedskadee National Wildlife Refuge right to 5,000 acre-feet of reservoir water are two exceptions to this. Enhancement or creation of wetlands is an environmental use that may see more development in the future, along with more applications for instream flow rights.

3.3 LEGAL AND INSTITUTIONAL SETTING

The legal framework that water users must operate within is defined by a mixture of state law, federal law, interstate agreements, and court decrees.

3.3.1 Wyoming Water Rights

Wyoming water law is the foundation upon which all water use, development, and protection are based. WWDC has stated that Wyoming water law shall be respected in all aspects of the water planning process. The water rights system in Wyoming is administered by the State Engineer's Office and the State Board of Control, which are constitutionally based administrative and quasi-judicial entities of state government.

Wyoming's water laws have evolved from the early establishment of legal principles that were later embodied in the State Constitution and a series of laws written and adopted early in Wyoming's history that have stood the test of time. One early water dispute that involved two territorial pioneers, William McCrea and Charles Moyer, is instructive regarding the history of water law in Wyoming. Moyer, whose name is associated with a now-famous spring in the coal-mining region north of Gillette, developed that spring for irrigation in 1890. Previously, McCrea had developed an irrigation project along the Little Powder River downstream of, and partially supplied by, Moyer's spring. With Moyer's development, McCrea's ditch was short of water, and the resulting argument eventually reached the Wyoming Supreme Court. In one of its first rulings on water matters, the Court affirmed the "first in time, first in right" doctrine by siding with McCrea. Through this 1896 ruling, the Court recognized the concepts of the prior appropriation doctrine that Territorial Engineer Elwood Mead had been advocating in the days leading to statehood and the constitutional conventions.

Mead, who became the first State Engineer, understood that water in an arid region must be administered in a predictable and equitable fashion, and the methods he fostered were to allow the earlier developer of water to establish the senior right for its continued use. The Wyoming State Constitution adopted this priority system of appropriation and established the position of State Engineer. Through the efforts of Mead, the Constitution also embodied the basis of appropriating water on the concept of "beneficial use" to avoid the potential for exaggerated amounts of water being tied up by early settlers and developers of water diversion systems. Mead also led the movement affirming a strong, active, independent state role in all aspects of appropriating and administrating the waters of the state as well as developing the process for resolving water disputes. Rather than use a water court system as in the neighboring state of Colorado, Wyoming established the State Board of Control within its Constitution. In addition to its independent authority to review matters initially decided by the State Engineer, the Board of Control is the adjudicator of all water rights and the decision-maker of all requests for changes to adjudicated water rights. The Constitution declares all water in the state to be the property of the state, subject to appropriation for beneficial use through the administrative permitting of water rights. Water rights are considered property rights that attach to the land or place of use. However, the law provides that the owner of these rights may change the location of use, or the type of use, by seeking approval from the Board of Control. The final decisions of the Board of Control are subject to judicial review. The Board of Control is made up of the State Engineer and the four Water Division Superintendents.

Within this constitutional framework, the detailed statutory authority, procedures, and administration were further defined by legislation and periodic Court decisions. The State Engineer's role is defined in Title 9, Chapter 1, Article 9, along with the general authority to establish fees for certain services and some other minor activities of the agency.

The majority of Wyoming's water laws are now codified primarily in Title 41 of Wyoming Statutes entitled "Water." Under this title, there are 14 chapters that include the authority and activities of the Water Development Commission and the laws associated with irrigation, drainage, watershed improvement, water and sewer districts, interstate compacts, and the use of watercraft. Chapters 3 and 4 contain the important laws relating to the appropriation, administration, and adjudication of water rights in Wyoming. These statutes relate to all waters of the state, whether they are from surface streams, springs, natural lakes, or underground waters.

The key elements of Wyoming's water laws were established in the Constitution and the early statutory laws before and near the turn of the century. From time to time, the legislature has modified the laws to address emerging new issues of the water users in the state. The laws addressing reservoirs were passed in the early 1900s; laws specific to groundwater sources were introduced in the 1940s and 1950s, with the last significant change adopted in 1969. Laws addressing instream flow water rights were codified in 1986. The basic framework of water right permitting actions and administration has remained the same, all the while allowing for flexibility in answering the needs of water users.

This set of laws is a part of the principles upon which the 2010 Green River Basin Plan is based.

3.3.2 Interstate Compacts, International Treaty, Court Decrees, Contracts, and Agreements

Colorado River Compacts (1922 and 1948)

A compact between the River Basin states (Wyoming, Colorado, New Mexico, Utah, Arizona, Nevada, and California) was negotiated in 1922. This compact allocated 7.5 million acre-feet of annual consumptive use to the Upper Basin. The Compact requires that Upper Division States not cause flow of the Colorado River at Lee Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of ten consecutive years. Lee Ferry is the point on the river dividing the Upper Basin from the Lower Basin. In addition, provision was made for future treaties with Mexico. As a result of this clause, the 1944 Colorado, Tijuana, and Rio Grande Treaty influences the regulation of the Colorado River. In 1948, a compact among the Upper Basin states was negotiated. It was ratified by all the states and the federal government in 1949. Arizona has a small area in the Upper Basin and therefore was included in the Upper Basin negotiations. This Upper Colorado River Basin Compact apportions the use allocated to the Upper Basin by the 1922 compact as follows: 50,000 acre-feet per annum to Arizona and of the remaining quantity 51.75 percent to Colorado, 11.25 percent to New Mexico, 23 percent to Utah, and 14 percent to Wyoming. The 1948 compact divided the waters of Henry's Fork between Wyoming and Utah on a straight priority basis for existing development. Waters of the Little Snake River used under rights existing prior to this compact and diverted below the river’s confluence with Savery Creek are administered on a straight priority basis (irrespective of the state line). Water uses developed after the compact’s signing are administered to equally share the available water supply.

3.3.3 Contracts and Agreements

Wyoming has also entered into several agreements that limit or modify water use at specific locations.

Fontenelle Reservoir Contract

Wyoming acquired the right to perpetually market 60,000 acre-feet of Fontenelle Reservoir storage from the United States Bureau of Reclamation (USBR) on two separate occasions. A Water Supply Act of 1958 authorized storage to meet anticipated future need for municipal and industrial purposes to be included in any reservoir project to be surveyed, planned, and constructed by the USBR – conditioned upon the willingness of state or local interests to pay for the cost of providing storage for the anticipated future demands. In 1959, the Wyoming Legislature appropriated the funds and authorized the

Natural Resource Board to enter into a contract with the USBR for storage in an amount not to exceed 60,000 acre-feet. In 1974, Wyoming entered into a second agreement with the USBR for an additional 60,000 acre-feet of storage. However, the agreement also gave Wyoming the ability to subcontract not more than 125,000 acre-feet annually, in essence providing conditions in which the State could over-sell.

The State of Wyoming, through the WWDC, has allocated 46,550 acre-feet of water to Jim Bridger Power Plant (35,000 acre-feet per year), FS Industries (10,000 acre-feet per year), Church and Dwight (1,250 acre-feet per year) and Exxon USA (300 acre-feet per year). Four water sale contracts have been executed. The contracts require remittance of a "readiness to serve fee," which reserves an amount of water specified in the contract which may be released as requested by the contractor. If all four contracts called for their associated releases, the amount of water released would total 46,550 acre-feet per year. Therefore, Wyoming has the right to market an additional 78,450 (125,000 less 46,550) acre-feet per year of Fontenelle Reservoir water.

High Savery Reservoir Contract

Construction of the High Savery Reservoir was authorized by the Wyoming Legislature to provide water for recreation, agriculture, municipal and domestic water supplies, environmental enhancement, and mitigation of the Cheyenne Stage I and Stage II transbasin diversion water supply projects. The permitted capacity of the reservoir is 22,433 acre-feet. A 5,724 acre-feet minimum pool requirement was stipulated in the Clean Water Act, Section 404 permit, issued by the U.S. Army Corps of Engineers (USCOE). The USCOE 404 Permit also mandated maintenance of a 12 cfs non-irrigation season releases to Savery Creek below the dam. If actual inflows are less than 12 cfs, the releases are required to match the actual reservoir inflows. Further, the state is to maintain a flow of 10 cfs from July 15 through September 15 below the dam regardless of reservoir inflows. The state has contracted with the Savery-Little Snake Water Conservancy District (District) for the sale of water residing above the elevation of the minimum pool. The District is responsible for remarketing water pursuant to the beneficial purposes described by the enabling legislation. The primary purpose of the reservoir is to provide firm, reliable late-season irrigation water, eight out of 10 years, to lands within the Little Snake River Basin.

3.3.4 Environmental Laws

The Environmental Quality Act was passed by the Wyoming Legislature in 1973. The purpose of the law was to address the concern that pollution "will imperil public health and welfare, create public and private nuisances, be harmful to wildlife, fish and aquatic life, and impair domestic, agricultural, industrial, recreational and other beneficial uses." The act authorized the state "to prevent, reduce and eliminate pollution; to preserve, and enhance the water and reclaim the land of Wyoming; to plan development, use, reclamation, preservation and enhancement of the air, land, and water resources of the state; to preserve and exercise the primary responsibilities and rights of the state of Wyoming; to secure cooperation between agencies of the state, agencies of other states, interstate agencies, and the federal government in carrying out these objectives" (Wyoming Environmental Quality Act, 1973).

The State of Wyoming has designated the Water Quality Division (WQD) of the Wyoming Department of Environmental Quality (WDEQ) to oversee water quality and enforce the water-related provisions of the Environmental Quality Act. This is being done through a number of programs that have been set up to control various forms of potential pollution. Pollution can come from point and nonpoint sources and can affect surface water and groundwater.

The WQD developed water quality standards, a result of the federal Clean Water Act, which are documented in Chapter 1, Wyoming Water Quality Rules and Regulations, and are available on the WQD website at http://soswy.state.wy.us/rules/search.htm. The surface water quality standards are based on four surface water classifications:

- **Class 1, Outstanding Waters**: Class 1 waters are surface waters in which no further water quality degradation by point source discharges other than from dams will be allowed. Nonpoint sources of pollution shall be controlled through implementation of appropriate best management practices. Water quality and physical and biological integrity which existed on the water at the time of designation will be maintained and protected. The designation of Class 1 waters is reflective of water quality. This includes the following characteristics: aesthetically pleasing, scenic, recreational, ecological, agricultural, botanical, zoological, municipal, industrial, historical, geological, cultural, archaeological, fish and wildlife habitat, the presence of significant quantities of developable water, and other values of present and future benefit to the people.
- **Class 2, Fisheries and Drinking Water**: Class 2 waters are waters, other than those designated as Class 1, that are known to support fish or drinking water supplies or where those uses are attainable. Class 2 waters may be perennial, intermittent or ephemeral and are protected for the uses indicated in each subcategory.
- **Class 3, Aquatic Life Other than Fish**: Class 3 waters are waters, other than those designated as Class 1, that are intermittent, ephemeral, or isolated and because of natural habitat conditions, do not support or have the potential to support fish populations or spawning; Class 3 includes certain perennial waters which lack the natural water quality to support fish (e.g., geothermal areas). Class 3 waters support invertebrates, amphibians, or other flora and

fauna which inhabit waters of the state at some stage of their life cycles. Uses designated on Class 3 waters include aquatic life other than fish, recreation, wildlife, industry, agriculture, and scenic value. Generally, waters suitable for this classification have wetland characteristics, and such characteristics are a primary indicator used in identifying Class 3 waters.

- **Class 4, Agriculture, Industry, Recreation and Wildlife**: Class 4 waters are waters, other than those designated as Class 1, where it has been determined that aquatic life uses are not attainable. Uses designated on Class 4 waters include primary contact recreation, wildlife, industry, agriculture, and scenic value.

Groundwater Quality

The State of Wyoming has identified the following standards for different classes of groundwater:

- Class I groundwater is defined as groundwater suitable for domestic use.
- Class II groundwater is defined as groundwater suitable for agricultural (irrigation) use where soil conditions and other factors are adequate.
- Class III groundwater is defined as groundwater suitable for stock use.
- Class Special (A) groundwater is defined as groundwater suitable for fish and aquatic life.
- Class IV groundwater is defined as groundwater suitable for industry.
- Class V groundwater is defined as groundwater found closely associated with commercial deposits of hydrocarbons, or groundwater which is considered a geothermal resource.
- Class VI groundwater is defined as groundwater that may be unusable or unsuitable for use.

Table 3-7 includes additional information regarding the standards for Classes I, II, and III.

The U.S. Environmental Protection Agency (USEPA) regulates public drinking water supplies in Wyoming since the state has not assumed primacy for this Clean Water Act program. This program provides comprehensive regulation of both surface and groundwater supplies, including enforceable standards for organic and inorganic constituents, complex filtration and disinfection requirements for surface water or groundwater determined to be under the influence of surface water, and monitoring and reporting requirements to ensure compliance. Although these rules and regulations continue to evolve, groundwater is widely considered to be a more desirable source of drinking water if it is available, due to substantially less expensive compliance requirements. Table 3-8 provides a partial listing of the inorganic constituents for which the USEPA has promulgated Maximum Contaminant Levels (MCL). “Primary” standards are based on human health effects and are required to be met. “Secondary” standards are based on the aesthetics of drinking water and are advisory.

Chapter 8 of the Wyoming Water Quality Rules and Regulations addresses groundwater quality standards and protection. These rules are enforced by WDEQ. Chapter 8 describes various classifications that have been created for groundwater and outlines the rules for discharges to these waters.

Table 3-7 - WDEQ Groundwater Quality Standards[1]

Constituent	Class I (domestic)	Class II (agricultural)	Class III (livestock)
	mg/L		
Chloride	250	100	2,000
Iron	0.3	5	
Sulfate	250	200	3,000
TDS	500	2,000	5,000
SAR[2]		8	

[1] Table only a partial listing of the standards.

[2] Sodium Adsorption Ratio (SAR) has been found to be important with respect to use of coalbed methane waters for irrigation.

Source: Wyoming Department of Environmental Quality, Water Quality Division. 2004. Wyoming Water Quality Rules and Regulations, Chapter 8.

Table 3-8 Drinking Water Standards

Constituent (unit)	USEPA Maximum Contaminent Level	
	Primary	Secondary
MAJOR IONS (mg/L)		
Chloride		250
Fluoride	4	2
Nitrogen, Nitrate+Nitrite as N	10	
Nitrogen, Nitrite as N	1	
Sulfate		250
NON-METALS (mg/L)		
Cyanide	0.2	
PHYSICAL PROPERTIES		
Color (color units)		15
Corrosivity (unitless)		non-corrosive
Odor (threshold odor number)		3
pH (standard units)		6.5 - 8.5
Total Dissolved Solids (mg/L)		500
Surfactants (methylene blue active substances)		0.5
METALS - TOTAL (mg/L)		
Aluminum		0.05 - 0.2
Antimony	0.006	
Arsenic	0.01	
Barium	2	
Beryllium	0.004	
Cadmium	0.005	
Chromium	0.1	
Copper	1.3	1
Iron	0.3	0.3
Lead	0.015	
Manganese		0.05
Mercury	0.002	
Nickel	0.1	
Selenium	0.05	
Silver		0.1
Thallium	0.002	
Uranium	0.03	
Zinc		5
RADIONUCLIDES - TOTAL (pico Curies per liter)		
Gross Alpha	15	
Gross Beta	50	
Radium 226 + Radium 228	5	

Source: USEPA Maximum Contaminant Levels (MCLs)

Surface Water Quality

The Clean Water Act requires that a 305(b) report be created which covers statewide water quality, along with a 303(d) list, of impaired streams in the state. Impaired streams require the establishment of total maximum daily loads (TMDLs) for problem pollutants. A TMDL is the amount of a specific pollutant that a water body can receive and assimilate in a given time period and still meet water quality standards.

The classification of a stream indicates what use is currently or can be supported by that stream. In general, the water quality in Wyoming is good based upon the number of water bodies supporting their designated uses. Wyoming's 305(b) State Water Quality Assessment Report produced by WDEQ includes 303(d) listings.

Colorado Basin Salinity Control Program

In order to comply with Section 303 (a) and (b) of the Clean Water Act, the Basin states established the Colorado River Basin Salinity Control Forum in 1973. Recently, the Forum published its "2008 Review, Water Quality Standards for Salinity, Colorado River System", which outlines policies that will affect some existing and future water development activities in Wyoming's Green River Basin. These policies are:

* Policy of Implementation of Colorado River Salinity Standards through the NPDES Permit Program. This policy applies to industrial and municipal discharges.

* Policy for Use of Brackish and/or Saline Water for Industrial Purposes. This policy applies to industrial water use.

* Policy for Implementation of Colorado River Salinity Standards through the NPDES Permit Program for Intercepted Ground Water. This policy applies to mines and wells which discharge intercepted ground water.

* Policy for Implementation of Colorado River Salinity Standards through the NPDES Permit Program for Fish Hatcheries. This policy applies to discharges from fish hatcheries.

For additional information regarding the Colorado River Basin Salinity Control Program, please visit http://www.usbr.gov/uc/progact/salinity/.

A technical memorandum summarizing this important institutional constraint was prepared as part of this plan. The reader is encouraged to consult that memorandum for in depth information (Wyoming State Engineer's Office, Tech. Memo, 2009(A).

WYDES Program

The EPA has delegated administration of the National Pollution Discharge Elimination System permitting program to the Wyoming Department of Environmental Quality, who in turn identifies it as the WYDES Program.

This program is a key permitting agency with respect to CBM and Natural Gas extraction activities. For additional discussion and information related to this program the reader is encouraged to consult the Institutional Constraints tech. memo and the Colorado River Basin Salinity Control Program tech. memo. Also the WYDES website address is http://deq.state.wy.us/wqd/WYPDES_Permitting/WYPDES_cbm/cbm.asp.

3.3.5 Federal Environmental Laws

Numerous federal legislative efforts have authorized the remediation and protection of water quality and the environment. These include the Clean Water Act, Pollution Prevention Act, Safe Drinking Water Act, Clean Air Act, NEPA, Solid Waste Disposal Act, Toxic Substance Control Act, and Federal Insecticide, Fungicide and Rodenticide Act. Most of the federal programs involved with water quality allow individual states to obtain primacy to administer the federal programs. The USEPA can step in if a state is not conducting the program to their satisfaction, even if the state has primacy.

The following is a list of water development and management actions that can initiate or trigger federal action or enforcement of environmental laws. A discussion of applicable federal legislation is presented following the list.

- Issuance and renewal of special use and right-of-way permits on federal lands.
- Contracting for storage water from federal reservoirs.
- Discharge of dredged and/or fill material into waters of the United States, including rivers, streams, and wetlands.
- Procurement and renewal of licenses from the Federal Energy Regulatory Commission (FERC) to produce hydropower.
- Use of federal loan or grant funds to construct a new water project or rehabilitate an existing water project.

Key applicable federal legislation includes the following acts:

Endangered Species Act

The Endangered Species Act of 1973 (ESA) requires the Secretary of Interior, through the U.S. Fish and Wildlife Service (USFWS), to determine whether wildlife and plant species are endangered or threatened based on the best available scientific information. The ESA constrains all federal agencies from taking any action that may jeopardize the continued existence of an endangered or threatened species. If a federal agency is considering an action that may jeopardize an endangered species, Section 7 of the ESA requires that the agency must consult with the USFWS.

Upper Colorado River Recovery Implementation Program

Since 1988, an innovative and cooperative program has been underway to resolve serious conflicts in the Upper Colorado River Basin between further development of Compact-apportioned water supplies and the conservation and recovery of four endangered fish species. The Upper Colorado River Endangered Fish Recovery Program is a multi-agency partnership to recover endangered fish in the upper Colorado River basin while water development proceeds in compliance with state and federal law (e.g., state water law, the Endangered Species Act, and interstate compacts).

Wyoming's participation in the Upper Colorado River Recovery Implementation Program facilitates the process by which most Wyoming projects within Wyoming’s portion of the Green River Basin obtain federal clearances under ESA. Rather than spending thousands of dollars on evaluations of potential impacts to the fish species and their designated critical habitat and developing expensive mitigation plans, a project proponent is able to pay a one-time charge for new depletions which are paid into a fund to benefit the endangered fish. The one-time charge is presently approximately $18 per acre foot of the estimated annual depletion. This amount is adjusted annually for inflation.

The Recovery Program was established in 1988 under a Cooperative Agreement signed by the Secretary of the Interior, the Governors of Colorado, Utah, and Wyoming, and the Administrator of the Western Area Power Administration. In December 2001, those same officials signed an extension of the Agreement that extended the program through September 30, 2013. An additional extension that will continue the Recovery Program through the end of fiscal year 2023, the date by which recovery of the four fish species (Colorado pikeminnow, the razorback sucker, the bonytail, and the humpback chub) will be completed pursuant to projections made in the four species’ recovery goals (published as part of their recovery plans), is in process currently.

National Environmental Policy Act

The National Environmental Policy Act of 1969 (NEPA) requires that federal agencies consider all reasonable foreseeable environmental consequences of their proposed actions. A review of an action under NEPA can be in the form of a categorical exclusion or environmental assessment (EA), both of which must result in a finding of no significant impact (FONSI), or an EIS and record of decision. Further, NEPA requires federal decision-makers to “study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources” (42 USC 4321 et seq., Sec. 102(2)E). NEPA provides federal agencies the opportunity to determine which alternative, including no action, they feel best serves the applicant's purpose and need. The alternative selected by the federal agency may differ from the one preferred by the applicant.

Clean Water Act

Section 404 of the Clean Water Act of 1972 prohibits discharging dredged or fill materials into waters of the United States without a permit from the USCOE. The waters of the United States include rivers and streams and, as of 1993, wetlands. USCOE policy requires applicants for 404 permits to avoid impacts to waters of the U.S. to the extent practicable, minimize the remaining impacts, and finally take measures to mitigate unavoidable impacts. In addition to the alternative review required by NEPA, Section 404(b)(1) guidelines require an alternative review to define the least environmentally damaging practicable alternative.

Section 401 of the Clean Water Act provides that the State of Wyoming certify any federally licensed or permitted facility which may result in a discharge into the waters of the state. The 401 certification provides a mechanism for Wyoming to amend, or perhaps veto, an action that the federal agency might otherwise permit. While the 401 certifications are required for several federal actions, most 401 certifications relate to Section 404 Dredge and Fill Permits required from the USCOE.

3.4 REFERENCES

Economic Analysis Division, Department of Administration and Information, State of Wyoming. Equality State Almanac 2007.

Northwest Alliance for Computational Science & Engineering, Oregon State University, PRISM, www.prism.oregonstate.edu.

Dams and Reservoirs Division, Wyoming Water Development Division, Fontenelle Dam and Reservoir, 2009

Wyoming Department of Environmental Quality, Water Quality Division. 2004. Wyoming Water Quality Rules and Regulations, Chapter 1.

Wyoming Department of Environmental Quality, Water Quality Division. 2004. Wyoming Water Quality Rules and Regulations, Chapter 8.

"Institutional Constraints," tech. memo, Wyoming State Engineer's Office, 2009 (A)

"Colorado River Basin Salinity Control Program," tech. memo, Wyoming State Engineer's Office, 2009 (B)

4.0 RESOURCES

4.1 INTRODUCTION

This chapter describes the quantity and quality of the Green River Basin's surface water and groundwater resources. Water quantity is the volume of water the Green River Basin might draw upon to sustain the local economy for present and future generations. Water quality is discussed in terms of the suitability of the water to meet a variety of uses. This chapter characterizes the Basin's total hydrologically available water supply irrespective of existing uses, institutional constraints, and speculations for how water resources might be put to future beneficial use. The results described in this chapter pertain to physical availability, which is different from legal or permitted availability, which is discussed in Chapter 7, Availability.

4.2 GENERAL

The Green River is the main drainage of the Green River Basin and a major tributary of the Colorado River. All the water draining to this river originates as precipitation, most of which evaporates from the surface or infiltrates the soil where it is stored and transpired by vegetation (annual evapotranspiration exceeds annual precipitation in this semiarid region). Precipitation and snowmelt, including glacier melt, that is not evaporated or stored in the soil profile either runs off, feeding rivers, streams, and lakes, or percolates downward through the soil profile to become groundwater. Surface water in the form of streams, lakes and reservoirs and groundwater resources in local and regional aquifers are the subject of this chapter.

4.3 SURFACE WATER RESOURCES

4.3.1 Quantity

Surface water quantity is recorded by U.S. Geological Survey (USGS) stream gaging stations at numerous locations as shown on Figure 4-1. At any given location, the flow recorded by a gage reflects depletions by upstream uses. Consumptive uses in the Basin are discussed in Section 5. Streamflow at any given location in the Basin varies from season to season and year to year as a function of the variability of precipitation in the region. For the purposes of this planning report, surface water quantity estimates were divided into three groups: dry years, average years, and wet years. For simplicity, it is assumed that the lowest 20% of the years (in terms of annual streamflow) are dry years, the highest 20% of the years are wet years, and the remaining years are considered normal years.

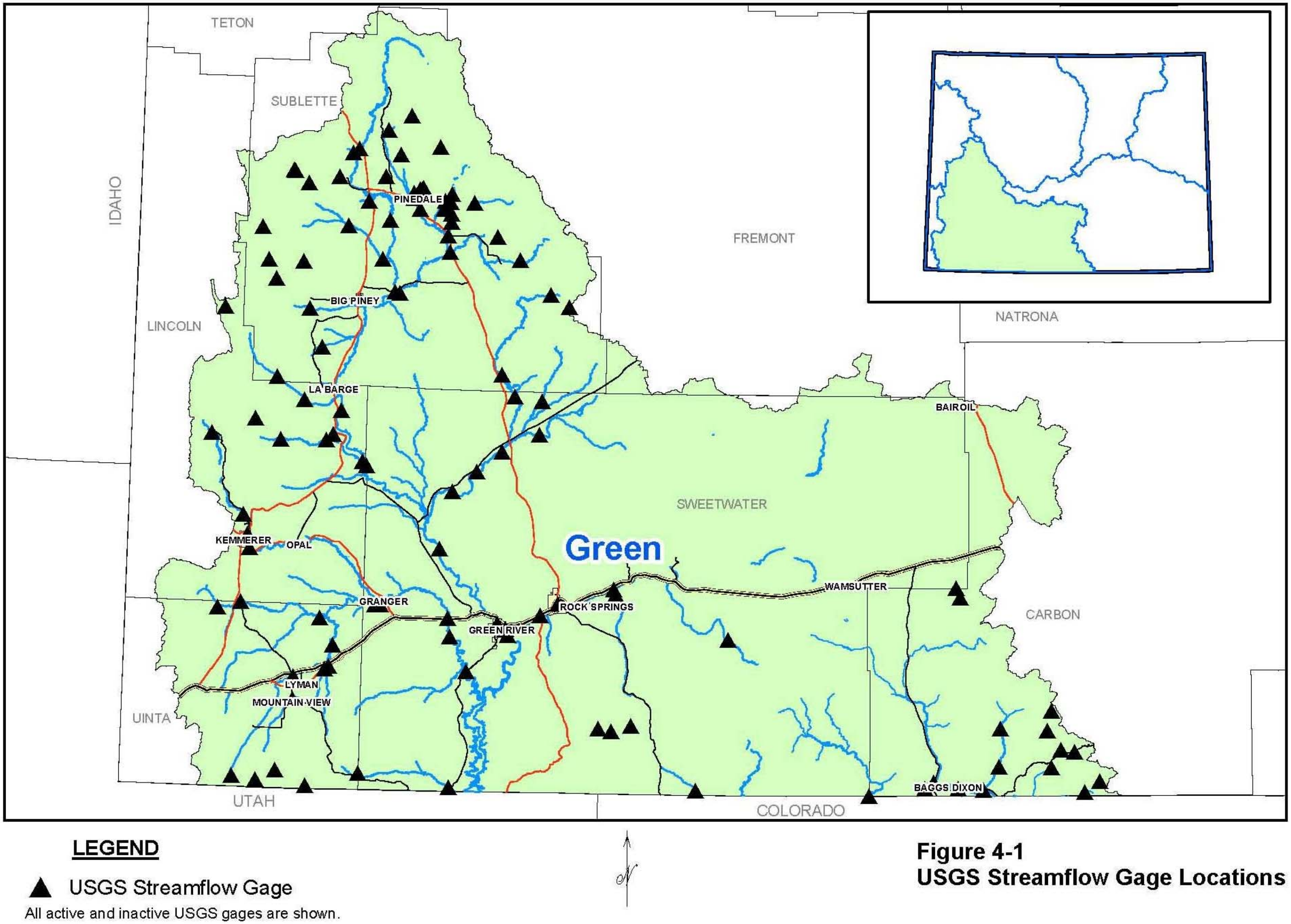


Figure 4-1
USGS Streamflow Gage Locations

Table 4-1 presents estimates of total surface water flow generated by the Green River Basin for dry, average and wet years. As the table shows, average year water supplies are about 235,000 acre-feet less than reported in the previous basin plan.

Table 4-1 - Total Surface Water Flow – Average Depletions Compared to Dry, Wet and Normal Flow Years

Sector of Water Use[1]	**Depletions Acre-Feet**		
Agricultural[2]	389,324		
Municipal[3]	21,859		
Domestic[4]	0		
Industrial[5]	56,833		
Recreational	non-consumptive		
Environmental	non-consumptive		
In-State Reservoir Evaporation[6]	121,300		
Total Depletions	**589,316**		
	Flow Leaving Green River Basin (Acre-Feet)[7]		
River	**Dry Year**	**Normal Year**	**Wet Year**
Green River	595,000	1,138,000	1,806,000
Little Snake River	177,000	407,000	642,000
Black's Fork River	67,000	195,000	398,000
Henry's Fork River	24,000	52,000	118,000
Total	**863,000**	**1,792,000**	**2,964,000**
Total Streamflow Volume plus Average Depletion	**1,452,316**	**2,381,316**	**3,553,316**
GRBP I Green River Total[8]	1,543,000	2,617,000	3,746,000
Change since 2001	-90,684	-235,684	-192,684

[1] Depletion estimates for each water use sector are from Chapter 5

[2] Agricultural surface water depletions consist of the irrigation depletion estimate, 396,246 ac-ft/yr, less the WSGS estimate for groundwater use for irrigation, 7,800 ac-ft/yr, plus one half of total stock use assuming that approximately 50% stock use is groundwater and the remaining 50% is surface water.

[3] Municipal use of 6,578 from Table 5-8 and 15,281 Cheyenne Diversions from Table 5-10.

[4] No domestic depletions from Table 5-8.

[5] Industrial depletion from Table 5-13.

[6] Evaporation estimate from 2001 Green River Basin Water Plan.

[7] From Table 2 in “Available Surface Water Determination,” tech. memo, AECOM, 2010.

[8] GRBP I Total Flow is from the 2007 Wyoming Framework Water Plan, Vol. 1, WWC Engineering

Streams in the Basin show wide fluctuations in seasonal flow in addition to annual fluctuations. A major portion of the annual stream flows is made up of snowmelt runoff occurring during the months of April, May, June, and July. The snow accumulates, particularly in the mountains, over the winter months. The average monthly flow of the Green River at Warren Bridge ranges from less than 10,000 acre-feet in the winter to over 100,000 acre-feet in June. This reach demonstrates the natural flow variation that is typical of Green River Basin streams when there is no control from large storage reservoirs or major diversions.

4.3.2 Water Quality

Water quality refers to a water's physical, chemical, radiological, biological, and bacteriological properties. The concentrations of dissolved and suspended components dictates the use-suitability of a water body, and sometimes institutional limits on concentrations of various components impose restrictions on use of certain water bodies for certain purposes. Water quality can be impacted by natural environmental processes and human activities. The success of a water development project is dependent upon the ability of the resource to meet the quality needs of the proposed use(s) without adversely affecting the water quality for other uses.

The complex geology of the Green River Basin influences the water quality characteristics of its streams. Streams which originate in the bedrock core of the mountains are generally clear and low in dissolved solids, while plains-area streams originate in softer, sedimentary rocks and are generally higher in dissolved and suspended solids. In the Green River Basin water quality analyses and regulations often focus on a project's tendency to increase salinity by concentration (e.g., by consuming water through evapotranspiration without consuming salts) or by salt loading (i.e., by adding to the total salt load of the streams) because of salinity concerns in the Colorado River Basin, particularly the lower basin.

Water salinity in the Colorado River Basin increases in a downstream direction. Some of this increase is natural, as the river flows from the mountainous areas of the upper basin toward the arid Southwest. Phreatophytes along the streams and evaporation from the water surface deplete water but leave the dissolved salts in the stream. Over the last century or so, increased use of water for irrigation, municipal and industrial uses and construction of large reservoirs have reduced streamflows and increased dissolved-solids levels in the river.

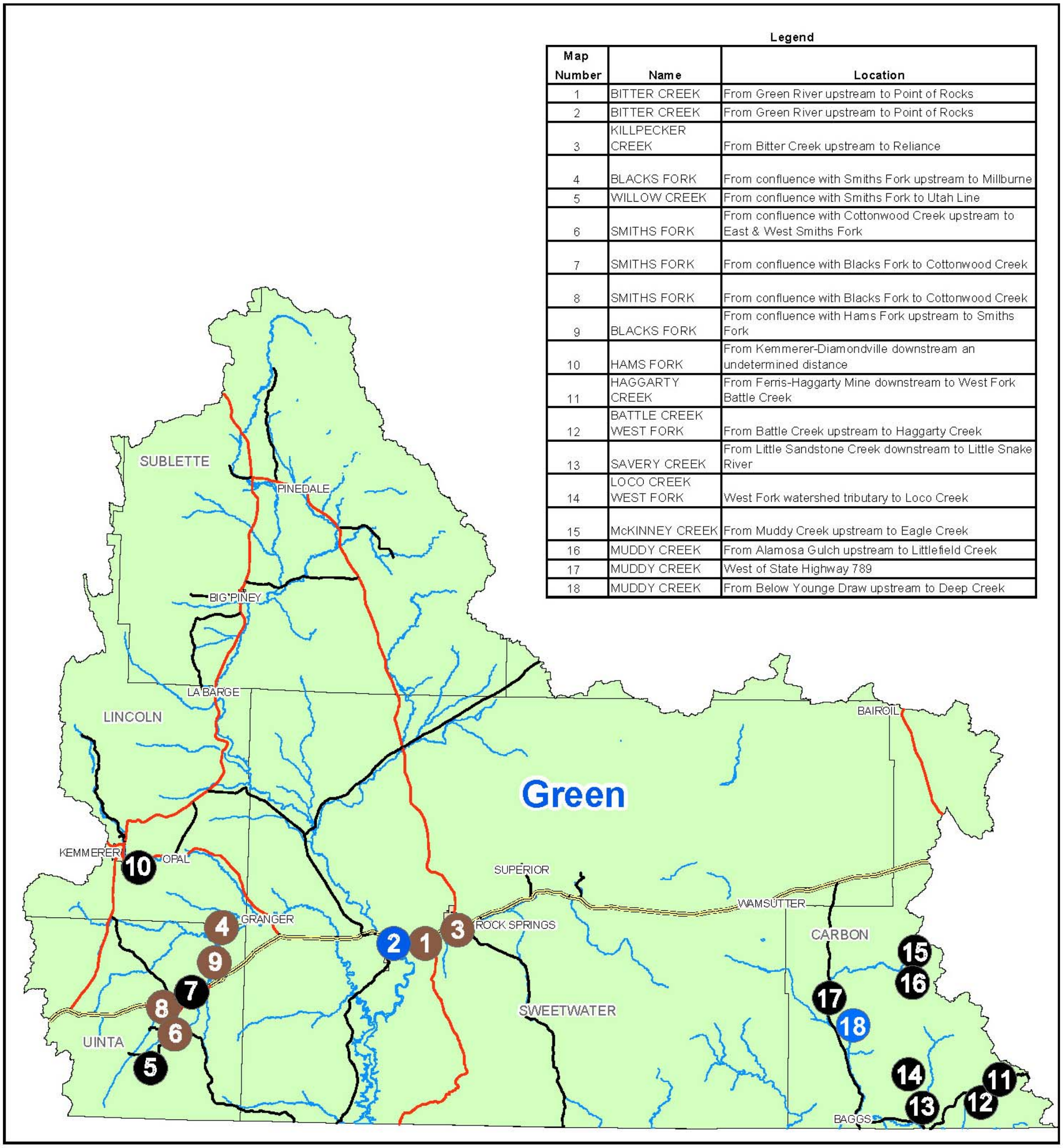
Concentrations of dissolved solids, phosphorus, suspended sediment, bacteria, and algae are generally lower in streams originating in the mountains compared to the concentrations found in streams originating on the plains. Invertebrates and fish found in the mountain streams are different from those in streams originating in the plains, partly as a result of the water quality differences. The water quality of streams originating in the mountains generally deteriorates as they flow across the plains and these water quality changes result from natural and man-made causes. Natural causes include increased availability of fine materials for transport and dissolution, less shading of the water by riparian vegetation, and less runoff per unit area in the plains than in the mountains to dilute salts. Man-made causes include irrigation return flow, livestock grazing, municipal sewage effluent, and industrial discharge.

Several stream segments in the Green River Basin are listed as impaired or threatened in Wyoming's Water Quality Assessment and Impaired Waters List (2010 Integrated 305(b) and 303(d) Report). These impaired waters require that a total maximum daily load (TMDL) not be exceeded. TMDLs must be established for each impairing pollutant in a stream and this measure of the ability of a water body to assimilate pollution while continuing to meet its designated uses helps in thorough watershed management, planning, as well as keeping solutions cost-effective. The primary sources of impairment are habitat degradation, pathogens and trace metals. Table 4-2 summarizes the 2010 303(d) List of Waters Requiring TMDLs and Figure 4-2 shows the stream segments affected.

Table 4-2 2010 303(d) List of Waters Requiring TMDLs

Basin*	303(d) ID	Name	Class	Location	Miles/ Acres	Uses	Use Support	Cause(s)	Source(s)	List Date
GR	WYGR140401050506_01	Bitter Creek	2C	From Green River upstream to Point of Rocks	21.6	Recreation	Not Supporting	Fecal Coliform	Unknown	2000
GR	WYGR140401050506_01	Bitter Creek	2C	From Green River upstream to Point of Rocks	21.6	Aquatic Life, Non- Game Fish	Not Supporting	Chloride	Natural Sources, Unknown	2002
GR	WYGR140401050808_01	Killpecker Creek	3B	From Bitter creek upstream to Reliance	6.9	Recreation	Not Supporting	Fecal Coliform	Unknown	2000
GR	WYGR140401070106_01	Blacks Fork	2AB	From confluence with Smiths fork upstream to Millburne	24	Recreation	Not Supporting	E.coli	Unknown	2000
GR	WYGR140401070205_01	Willow Creek	2AB	From confluence with Smiths Fork upstream to Utah Line	48.5	Aquatic Life, Cold Water Fish	Threatened	Habitat	Grazing	1998
GR	WYGR140401070208_00	Smiths Fork	2AB	From confluence with Cottonwood Creek upstream to east and West Smiths Fork	29.6	Recreation	Not Supporting	Fecal Coliform	Unknown	2002
GR	WYGR140401070208_01	Smiths Fork	2AB	From confluence with Blacks Fork to Cottonwood Creek	3.6	Aquatic Life, Cold Water Fish	Not Supporting	Habitat	Unknown	2000
GR	WYGR140401070208_01	Smiths Fork	2AB	Form confluence with Blacks Fork to Cotton wood Creek	3.6	Recreation	Not Supporting	E.coli	Unknown	2002
GR	WYGR140401070403_01	Blacks Fork	2AB	From confluence with Ham's Fork upstream to Smiths Fork	44.1	Recreation	Not Supporting	E.coli	Unknown	2000
GR	WYGR140401070701_01	Hams Fork	2AB	From Kemmerer-Diamondville downstream an undetermined distance	7.8	Aquatic Life, Cold Water Fish	Not Supporting	pH	Municipal WWTF	1996
LS	WYLS140500030109_01	Haggarty Creek	2AB	From Ferris-Haggarty Mine downstream to West Fork Battle Creek	5.9	Aquatic Life, Cold Water Fish	Not Supporting	Cd, Cu, Hg	Hardrock Mining	1996
LS	WYLS140500030109_02	Battle Creek West Fork	2AB	From Battle Creek upstream to Haggarty Creek	4.6	Aquatic Life, Cold Water Fish	Not Supporting	Cu	Hardrock Mining	2000
LS	WYLS140500030408_01	Savery Creek	2AB	From Little Sandstone Creek downstream to Little Snake River	11.4	Aquatic Life, Cold Water Fish	Threatened	Habitat	Grazing	1998
LS	WYLS140500030408_02	Loco Creek West Fork	2AB	West Fork watershed tributary to Loco Creek	2.8	Aquatic Life, Cold Water Fish	Threatened	Habitat, Nutrients, Temp.	Grazing	1996
LS	WYLS140500040102_01	McKinney Creek	2AB	From Muddy Creek upstream to Eagle Creek	5.1	Aquatic Life, Cold Water Fish	Threatened	Habitat	Grazing	1996
LS	WYLS140500040103_01	Muddy Creek	2AB	From Alamosa Gulch upstream to Littlefield Creek	11.4	Aquatic Life, Cold Water Fish	Threatened	Habitat	Grazing	1996
LS	WYLS140500040104_01	Muddy Creek	2C	West of State Highway 789	15.4	Aquatic Life, Non-Game Fish	Threatened	Habitat	Grazing	1996
LS	WYLS140500040308_01	Muddy Creek	2C	From below Young Draw upstream to Deep Creek	7.5	Aquatic Life	Not Supporting	Se, Cl	Unknown	2010

* GR-Green River Basin; LS-Little Snake River Basin



Legend

Map Number	Name	Location
1	BITTER CREEK	From Green River upstream to Point of Rocks
2	BITTER CREEK	From Green River upstream to Point of Rocks
3	KILLPECKER CREEK	From Bitter Creek upstream to Reliance
4	BLACKS FORK	From confluence with Smiths Fork upstream to Millburne
5	WILLOW CREEK	From confluence with Smiths Fork to Utah Line
6	SMITHS FORK	From confluence with Cottonwood Creek upstream to East & West Smiths Fork
7	SMITHS FORK	From confluence with Blacks Fork to Cottonwood Creek
8	SMITHS FORK	From confluence with Blacks Fork to Cottonwood Creek
9	BLACKS FORK	From confluence with Hams Fork upstream to Smiths Fork
10	HAMS FORK	From Kemmerer-Diamondville downstream an undetermined distance
11	HAGGARTY CREEK	From Ferns-Haggarty Mine downstream to West Fork Battle Creek
12	BATTLE CREEK WEST FORK	From Battle Creek upstream to Haggarty Creek
13	SAVERY CREEK	From Little Sandstone Creek downstream to Little Snake River
14	LOCO CREEK WEST FORK	West Fork watershed tributary to Loco Creek
15	McKINNEY CREEK	From Muddy Creek upstream to Eagle Creek
16	MUDDY CREEK	From Alamosa Gulch upstream to Littlefield Creek
17	MUDDY CREEK	West of State Highway 789
18	MUDDY CREEK	From Below Younge Draw upstream to Deep Creek

Source: Wyoming Water Quality Assessment and Impaired Waters List (2010 Integrated 305(b) and 303(d) Report)

LEGEND

- Fecal Coliform
- Chloride
- Other (Phosphate, pH, Habitat, Metals, Oil, Ammonia, and Temp)

N

Figure 4-2
2010 303(d) Waters With Water Quality Impairments

4.4 GROUNDWATER RESOURCES

4.4.1 Groundwater Overview

In the Green River Basin, groundwater resources occur within both unconsolidated deposits and bedrock formations and show a wide range of variability in quality and quantity available. Groundwater information presented in this section comes mainly from the Wyoming State Geological Survey's *Available Groundwater Determination, tech. memo, 2010.*

Groundwater originates when rainfall, snowmelt, stream flow, and, in some areas, irrigation water infiltrate into geologic materials, a process called groundwater "recharge". Over time, groundwater travels through the subsurface and returns to the surface as discharge. Between the points of recharge and discharge, groundwater flow may be straightforward or quite complex. Because groundwater is continually returning to the surface as springs and as diffuse gains to perennial streams, streamflow records include varying quantities of groundwater. In the absence of storm runoff or snowmelt, most of the flow in the Basin's streams is supplied from groundwater. In general, shallow groundwater flow (less than 300-500 feet beneath the surface) follows topography and is discharged to stream and river drainages.

Groundwater enters and leaves the state in the subsurface, but no estimates of rates or locations have been compiled. It is simply understood that more groundwater leaves the state than surface water. Although the area through which groundwater flow leaves the state is vastly larger than that through which surface water exits, groundwater velocities are typically measured in feet per day, whereas surface velocities are typically measured in feet per second.

In areas of shallow groundwater, groundwater levels commonly rise in response to spring precipitation and snowmelt and fall to annual lows in midwinter due to the absence of recharge. In aquifers remote from surface influence, there may be little or no annual fluctuation, but groundwater levels may still rise and fall in response to long-term climate cycles. Individual well hydrographs vary widely, as a function of local hydrogeologic and groundwater conditions and groundwater use rates.

Within the Green River Basin, most of the water-saturated portions of the geologic bedrock formations and unconsolidated deposits will yield groundwater to wells. Groundwater in bedrock formations flows predominantly through permeable rocks and fractures from aquifer recharge areas located along the margins of the Basin towards the center of the Basin and down-gradient to the south-southwest into Utah. Shallow groundwater flow in the Green River Basin is predominantly controlled by topography and stream drainage patterns. The Great Divide Basin has an internal drainage and the groundwater flow, like the surface water flow, is towards the center of the Basin.

Four major regional aquifer systems have been identified in the Green River Basin based upon the four geologic eras: the Cenozoic, Mesozoic, Paleozoic, and Precambrian (ordered youngest to oldest). These four major aquifer systems are described below.

- **Cenozoic Major Aquifer System**- is the youngest and most heavily used group of aquifers in the Basin. The water-saturated portions of this system include unconsolidated gravel and sand alluvial deposits, tertiary sedimentary rocks such as sandstone, conglomerate, and conglomeratic sandstone, and coal beds. This system includes Quaternary-age sands and gravels associated with major river courses and the very productive Tertiary-age aquifers. The Tertiary and overlying Quaternary aquifers make up 83 percent of the surficial geology of the Green River Basin.

- **Mesozoic Major Aquifer System-** is the second most utilized aquifer system in the Basin. This system consists of water-bearing sandstone, conglomerate, conglomeratic sandstone, and carbonate beds separated by confining shale units. This system includes the Mesaverde-Adaville aquifers, the Frontier aquifer, Upper Jurassic-Lower Cretaceous age aquifers, and the Sundance-Nugget aquifer system.

- **Paleozoic Major Aquifer System-** is the third most used aquifer system in the Basin. The water-bearing units in this system consist of mainly carbonates and sandstones. This system includes the Madison Limestone and the Flathead aquifer.

- **Precambrian Major Aquifer System-** is the oldest and least used system of aquifers. This unit is comprised of old crystalline crustal rocks forming the deepest bedrock beneath the Basin and are only exposed at or near the surface in the cores of mountain uplifts at the rim of the Basin. The most productive water wells in this unit are located in mountainous outcrop zones; elsewhere this unit does not support large-yielding wells.

4.4.2 Aquifer Classification

Aquifers are formations, groups of formations, or parts of a geologic formation that contain sufficient water-saturated highly-permeable material to yield significant quantities of water to wells and springs. Classification of a body of geologic material as an “aquifer” depends on how much water is yielded for a specific user or purpose. A hydrogeologic formation capable of adequately supplying the modest water needs of a single rural residence is considered an aquifer for that purpose, even though it may be entirely inadequate to meet the needs of a large agricultural operation. Several classes of aquifers are described in this section based on the state-wide framework plan (WWC Engineering, 2007), and Figure 4-4 illustrates the aerial distribution of the primary water-bearing units in the Green River Basin.

Major Aquifers

Alluvial

These aquifers consist of highly permeable sand and gravel beds in alluvial deposits located along rivers and streams and include some of the best-yielding aquifers in the Basin, with wells producing anywhere from 10 to 500 gallons per minute (gpm). The productivity of these aquifers is greatly reduced in areas where the deposits are thin or contain abundant clay or silt.

Generally, the most productive alluvial aquifers are in the upper reaches of major streams where the alluvial materials are predominantly coarse gravel and sand. The alluvial deposits tend to become finer-grained as the streams progress away from the mountains into the interior basins. Where the alluvial aquifer is associated with an active stream, interception of groundwater headed for the stream or induced infiltration from the stream may provide most of the available groundwater to wells; stream depletion rates may approach pumping rates over relatively short time periods. Where closely associated with surface streams, alluvial aquifer quality tends to be good due to the low salinity of water in the stream and good hydraulic communication between the stream and the aquifer.

Sandstone

These aquifers consist of consolidated rock formations composed mostly of permeable sandstone and conglomerates. These aquifers have the potential to develop large quantities of good quality groundwater although water quality is highly variable in the main water-bearing Tertiary aquifers. Most of the deposits and formations in this group include zones of poor production due to local clay content or lack of fractures.

The major sandstone aquifers generally crop out on the flanks of the Green River Basin's mountain ranges, and commonly dip into the Basin, where they may provide useful water supplies even considerable distances from the outcrop areas shown in Figure 4-3. In the Basin interior, the sandstone aquifers tend to be widespread and gently dipping. The most productive formations of this group are the thick, Tertiary-age sandstones, where local faulting and fracturing enhance permeability and therefore water productivity. However, not all sandstone layers are thick and continuous. There are also many discontinuous layers and lenses that require penetration of a substantial number of individual beds to produce the desired amount of water. Major sandstone and conglomerate aquifers include the Battle Spring formation, Wasatch Formation, Fort Union Formation, Mesaverde Group, Cloverly Formation, and Nugget Sandstone.

Limestone

These aquifers consist of bedrock formations composed of a majority of carbonates (limestone or dolomite/dolostone) and have the potential to develop large quantities of good quality groundwater. The productivity of these aquifers is almost entirely dependent upon fractures and karstic solution features, created by deformation and groundwater circulation, both of which are the most developed along the Basin's margin. More than with any other major aquifers, local conditions are the key to successful groundwater development. Major carbonate aquifers include the Tensleep Sandstone, Weber Sandstone, and Flathead Formation as well as the Madison Limestone and Bighorn Dolomite.

Formations	Standard Map Symbols[1]	Dominant Lithology	Basins of Occurrence[2]: BE	GR	NE	PL	PT	SS	WB	Thickness, ft: 100	200	300	500	1,300	2,500	3,000	>5,000	Yields, gpm: 5	10	15	20	100	250	1,000	>1,000	TDS, mg/L: 100	300	500	1,000	3,000	>4,000
Alluvium	Qa, Qt	sand, gravel, silt, clay	●	●	●	●	●	●	●	■	■															■	■	■	■	■	■
Ogallala	Tmu	sandstone, siltstone, gravel				●				■	■	■										■	■	■	■	■	■	■			
Teewinot and Salt Lake	Tte, Tsl	tuff, limestone, claystone						●		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Arikaree, North Park, Splitrock	Tmo, Tm, Tmu	sandstone (tuffaceous)			●	●				■	■	■	■					■	■	■	■	■	■				■	■			
Bridger, Battle Springs, Fowkes	Tb, Tbs, Tf	sandstone, conglomerate	●	●						■	■	■	■	■	■	■															
Wasatch, Wind River	Tw, Twdr, Twk, Twm, Twmo	siltstone, sandstone, shale	●	●	●	●	●		●			■	■	■	■					■	■	■	■			■	■	■	■	■	■
Fort Union - various members	Tfu, Tfl, Tflt, Tftr	sandstone, siltstone, coal		●	●		●							■	■	■					■	■	■					■	■	■	■
Lance	Kl	sandstone, siltstone			●		●						■	■	■	■		■	■	■	■	■	■					■	■	■	
Fox Hills	Kfh, Kfl, Kfb	sandstone, shale			●		●			■	■	■	■					■	■	■	■	■	■	■				■	■	■	
Mesaverde and related rocks	Kmv, Kav, Kal, Ke, Kr, Kbl	sandstone, shale, coal	●	●													■														
Cloverly/Dakota	KJ, KJs, Kg	sandstone, siltstone	●	●	●		●			■	■	■						■	■	■	■	■	■				■	■	■	■	
Nugget	J₹n	sandstone	●	●				●					■																		
Casper, Tensleep, Minnelusa, Hartville	P₱c, P₱cf, P₱h, P₱m, PM, P₱M	sandstone & limestone, shale	●	●	●	●	●	●	●	■	■	■	■	■	■						■	■	■	■		■	■	■	■	■	
Madison, Bighorn	Mm, MD, MDO, MDe, MDg, MO, O€, Ob, Pzr	limestone, dolomite	●	●	●	●	●	●	●				■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	
Flathead	€r	sandstone	●	●					●		■																				
Non-alluvial Deposits	Ql, Qg, QTg, Qls, Qs	landslide debris, glacial deposits	●	●	●	●	●	●	●	■								■	■	■	■					■	■	■			
Arikaree	Tmo, Tmu	sandstone (tuffaceous)					●			■	■	■	■					■	■	■	■	■	■	■							
Willwood	Twl	sandstone, siltstone, mudstone							●								■	■	■	■	■										
Ft Union	Tfu	sandstone, claystone, coal				●			●								■				■	■	■				■	■	■	■	■
Evanston	Tke	conglomerate, sandstone	●	●										■	■	■															
Lance, Fox Hills	Kl, Klm	sandstone, shale, siltstone		●		●			●								■	■	■	■	■	■	■				■	■	■	■	■
Medicine Bow	Kmb	sandstone, shale				●											■										■	■	■	■	
Mesaverde	Kmv	sandstone, shale				●	●		●				■	■	■	■					■	■	■			■	■	■	■		
Frontier	Kf, Kft	sandstone and shale	●	●		●	●	●	●				■	■	■	■		■	■	■	■	■	■			■	■	■	■	■	
Cloverly (Dakota), Morrison	KJ, K , KJs, KJg	sandstone, shale				●			●	■	■	■	■					■	■	■	■	■				■	■	■	■	■	■
Sundance, Nugget and related rocks	Js, Jsg, J₹, J₹n	sandstone, siltstone, gypsum			●	●			●				■	■	■			■	■	■	■	■	■			■	■	■	■	■	
Twin Creek and Thaynes	J₹nd, Jst	limestone, shale	●	●				●						■	■																
Spearfish	₹Ps	shale, siltstone			●								■							■											
Phospohoria, Minnekahta	Pp, Pmo, MzPz	limestone, siltstone, sandstone	●	●	●			●	●			■						■	■	■	■	■	■	■							
Bighorn, Flathead	DO, €r	dolomite, limestone, shale, sandstone							●						■			■	■	■	■	■	■	■	■						
Gallatin, Gros Ventre, Flathead	€r	limestone, sandstone, shale				●	●						■													■	■	■			
Quaternary Deposits	Qg, Qls, Qs, Qu	sand, gravel, silt, boulders							●	■								■	■	■	■	■	■	■	■						
Volcanic rocks	Qb, Qr, Thr, Ti, Tii, Tcv, Tts, Twi, Ttl, Tt, Ts, Ttp, Twp, Taw, Tv	lava flows, mudflows, ash, tuff, breccia						●	●								■	■													
Camp Davis, Colter, Hoback	Tcd, Tc, Th	conglomerate, mudstone						●									■	■	■												
White River	Twr, Twru, Twrb, Twrc	siltstone, claystone			●	●	●							■	■					■	■	■	■			■	■	■	■		
Wagon Bed, Crandall	Twb, Teml, Tcr, TKu	sandstone, siltstone, mudstone				●			●				■					■	■										■	■	
Hanna	Tha	shale, sandstone, coal				●											■				■	■	■					■	■	■	■
Ferris	TKf	sandstone, shale, conglomerate				●											■	■	■	■	■	■	■				■	■	■	■	■
Sohare, Harebell	Kso, Ksb, Kha, Kb	sandstone, shale, siltstone						●									■	■	■	■	■										
Aspen, Bear River	Ka, Kbr, Kg	shale, sandstone, siltstone						●								■	■	■	■	■	■										
Sundance	Js, Jsg	shale					●					■																			
Chugwater and related rocks	₹c, J₹gc, J₹gn, ₹cd, ₹Pcg, ₹Pg	siltstone, sandstone, gypsum							●					■	■			■	■	■	■										
Woodside and Dinwoody	J₹ad, ₹cd	siltstone, shale	●	●				●			■	■	■	■	■																
Amsden	P₱Ma, P₱M	shale							●				■																		
Indian Meadows	Tim	claystone							●				■																		
Meetsetse and Lewis	Km, Kle, Kml	siltstone, claystone, shale	●	●			●		●					■	■																
Cody, Pierre, Steele, Niobrara, Baxter, Carlisle	Kc, Kp, Ks, Kn, Knc, Kcl, Kgb, Kgbm, Kh, Kba	shale	●	●	●	●	●	●	●								■														
Thermopolis, Mowry, Aspen	Kmt, KJk, Kmr, Kgb, Kgbm, Kns, Ka, Kbr	shale	●	●	●	●	●		●						■																
Chugwater, Goose Egg	₹c, ₹cd, ₹Ps, ₹Pcg, ₹Pg	siltstone, sandstone, gypsum				●	●						■																■	■	
Precambrian rocks		granite, gneiss, schist	●	●	●	●	●	●	●								■									■	■				

[1] Map symbols for the Geologic Map of Wyoming (Love and Christiansen, 1985)

[2] BE - Bear; GR - Green; NE - Northeast Wyoming; PL - Platte; PT - Powder/Tongue; SS - Snake/Salt; WB - Wind/Bighorn

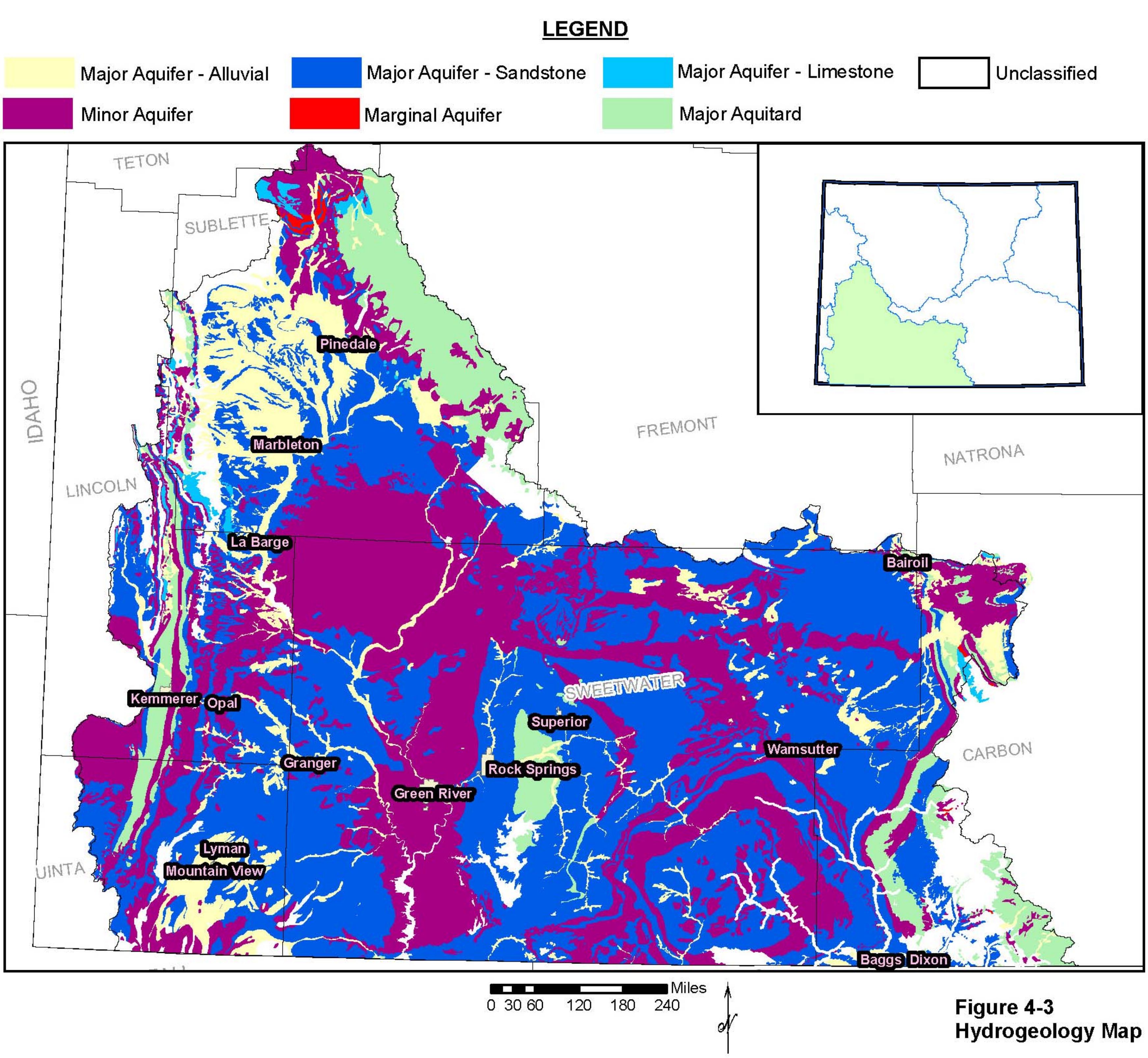


Figure 4-3
Hydrogeology Map

Minor Aquifers

Minor aquifers often have thinner beds that are less permeable and less laterally extensive as compared to major aquifers, but commonly provide useful groundwater supplies for small uses such as domestic and stock water supplies. These geologic units typically have lower yielding wells (50 gpm or less) and the groundwater quality from these aquifers is variable, largely as a function of distance from a recharge source. Productivity is largely a function of the thickness and texture of sandstone units, although fracture enhancement of permeability can make the difference between unacceptable and acceptable production rates. Examples of minor aquifers include Quaternary non-alluvial deposits, the Frontier, Evanston, Lance, and Phosphoria formations as well as the Twin Creek Limestone, Fox Hills Sandstone and the Thaynes Limestone.

Marginal Aquifers

Most geologic formations can provide useful groundwater supplies under the right conditions, particularly if the demands are small, as for stock and domestic use. Marginal aquifers are typically bedrock formations with very low yielding wells (1-5 gpm) and very little potential for developing moderate to large quantities of good quality groundwater. These aquifers are generally suitable for low-yielding domestic or stock wells. Examples of marginal aquifers include the Woodside and Dinwoody formations.

Major Confining Units (Aquitards)

These formations are typically poor producers of groundwater and the water is usually of poor quality. The sedimentary forms of these geologic units are predominantly composed of a high percentage of shale and show little potential for producing useable quantities of groundwater. Many of these low permeability, confining units are composed of thick, laterally extensive sequences of marine shale. Because of their clay content, these rocks are less brittle than sandstone or granite and are thus less susceptible to the permeability enhancement of fractures. These thick confining units act as regional seals between aquifers and greatly decrease permeability for vertical groundwater flow.

The crystalline rocks of the Precambrian aquifer system which form the mountain cores and underlie the entire Green River Basin are typically a major basal confining unit as they are located beneath sedimentary rock formations in the structural basins. The absence of fractures and nature of these types of Precambrian basement rocks makes them virtually impermeable.

Examples of confining units include the Cody, Steele, Baxter, Thermopolis, Mowry, and Aspen shales as well as the Niobrara Formation and deeply buried Precambrian basement rock units.

Unclassified

These geologic materials are present in limited areas without adequate hydrogeologic data available for classifying the geologic unit.

Aquifer Location

Aquifers are most convenient to use when they are near the surface where water is shallow (less than 500 feet deep) and usually has the best quality. Figure 4-3 shows where specific aquifer groups are present near the surface, called aquifer outcrops. Most of the water-bearing aquifer bedrock formations in the Green River Basin crop out in the highland and mountainous margins of the Basin and are covered by younger formations towards the lowland centers of the Basin. Thus groundwater is commonly available from productive basin-margin aquifers for some miles basinward of the outcrops depicted on Figure 4-3, albeit at increasing depth.

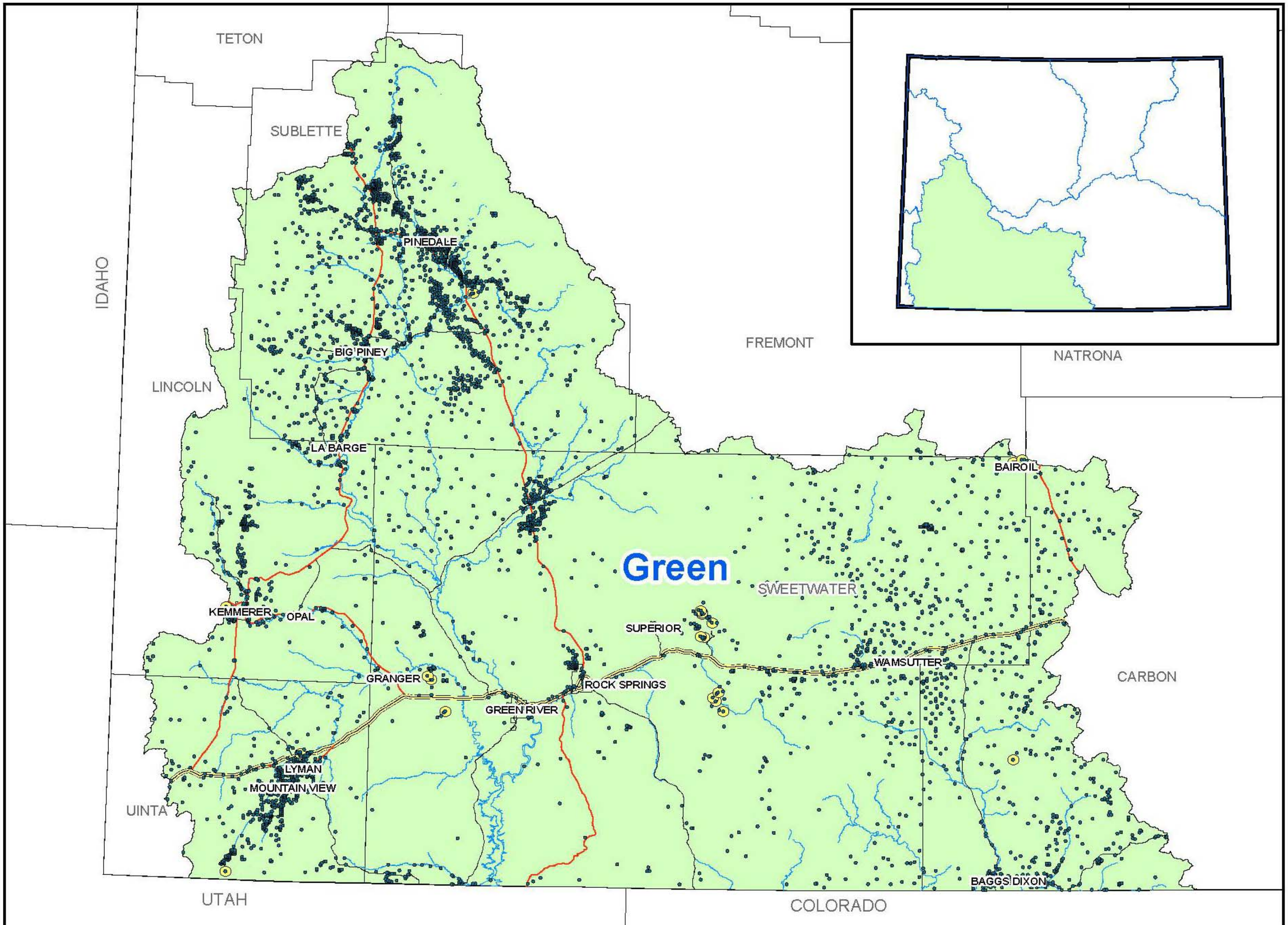
Where a productive aquifer is overlain and underlain by a confining unit (considered to be impermeable or characterized by very low permeabilities) the water contained therein is under pressure, producing artesian conditions which may result in flowing wells where the confining unit is punctured. Many aquifers of the Green River Basin are confined, including many in the Mesozoic aquifer system due to the numerous confining layers of shale present in this system.

For consolidated bedrock aquifers, geologic structures such as folds and faults are as important as rock type in providing useful supplies of groundwater. The rocks are generally fractured in these geologic structures. The fractures provide secondary permeability in rocks that have very little inherent or primary permeability and serve as conduits of flow that can increase groundwater productivity. In the Green River Basin, major belts of faulting occur along the mountains where deformation has taken place due to mountain-building. Large-scale fracturing in the interior of the Basin is much less prevalent, and grain size and degree of cementation of aquifer materials plays the primary role in determining aquifer productivity.

Optimum conditions for the development of groundwater reflect the conjunction of favorable aquifer formations, good permeability within those formations (primarily due to coarse-grained materials and/or fractures in the rock) and recharge conditions that provide suitable groundwater quality.

4.4.3 Historical Aquifer Performance

There has been relatively little development of the groundwater resources of the Green River Basin. Figure 4-4 shows all water wells for which permitted yield is greater than zero excluding coalbed methane (CBM) also known as coalbed natural gas wells. Areas of low well density reflect either small populations or lack of available water from low-producing aquitards such as the shale located just east of Rock Springs. Highlighted wells on Figure 4-4 indicate production rates of 500 or more gallons per minute, an indication of high aquifer productivity.



LEGEND

● Active Well ○ Active Well, > 500 gpm

Source: Wyoming State Engineer's Office GIS files compiled June 2006

Figure 4-4
Active Wells

These wells mark aquifers with adequate permeabilities, depth, quality, and convenience of location to serve the Basin's major needs. As of December 2007, more than 13,000 groundwater permits had been issued by the Wyoming State Engineer's Office in the Basin. Most of these wells are less than 300 feet deep (88.6%) and yield 25 gallons per minute (gpm) or less (95.2%). There are 19 permitted groundwater wells with yields listed as more than 500 gallons per minute in the Green River Basin.

4.4.4 Groundwater Quality

Most activities which affect the quality of groundwater in Wyoming are regulated by the Wyoming Department of Environmental Quality (WDEQ), Water Quality Division (WQD), while the U.S. Environmental Protection Agency (USEPA) Region 8 office headquartered in Denver, Colorado, regulates the public water systems located within the state. Each agency has established groundwater standards, which are revised and updated as needed.

The State of Wyoming through the WDEQ/WQD has classified groundwater of the state in the *Water Quality Rules and Regulations, Chapter 8—Quality Standards for Wyoming Groundwaters,* according to these criteria:

- Class I Groundwater of the State—Groundwater quality that is suitable for domestic use.
- Class II Groundwater of the State—Groundwater quality that is suitable for agricultural use where soil conditions and other factors are adequate for such use.
- Class III Groundwater of the State—Groundwater quality that is suitable for livestock watering.
    - Class Special III (A) Groundwater of the State—Groundwater quality that is suitable for fish and aquatic life.
- Class IV Groundwater of the State—Groundwater quality that is suitable for industrial use.
    - Class IV(A) Groundwater of the State—Groundwater quality that has a total dissolved solids (TDS) concentration that is not in excess of 10,000 milligrams per liter (mg/l). This level of groundwater quality in an aquifer is considered by the USEPA under the Safe Drinking Water Act (SDWA) provisions as a potential future drinking water source with water treatment.
    - Class IV(B) Groundwater for the State—Groundwater quality that exceeds a TDS concentration of 10,000 mg/l.
- Class V Groundwater of the State—Groundwater quality as found in close association with commercial deposits of hydrocarbons (oil and gas)(Class V Hydrocarbon Commercial) and/or other minerals (Class V Mineral Commercial), or is a geothermal energy source (Class V Geothermal).
- Class VI Groundwater of the State—Groundwater quality which may be unusable or unsuitable for use.

Groundwater quality in the Green River Basin is highly variable, even within a single geologic unit. The Basin lies largely on sediments derived from prehistoric seas, so soils naturally contain salts which are dissolved by groundwater. Water quality in any given geologic unit tends to be better near outcrop areas where recharge occurs and deteriorates as the distance from these areas increases (and also as residence time increases). The water quality of a given geologic unit also usually deteriorates with depth. Groundwater quality concerns in most of the Green River Basin aquifers will generally limit new water well construction to depths of 1,000 feet or shallower, especially for the Tertiary, Mesozoic, and Paleozoic aquifers. This indicates that groundwater development for these aquifers is generally limited to aquifer outcrop areas or within a distance of one to three miles of these outcrops.

Total Dissolved Solids (TDS) concentration is a useful measure of a water's suitability for human, agricultural, environmental and industrial uses (See Chapter 3 for TDS standards). TDS concentrations in groundwater of most geographic regions within the Green River Basin tend to exceed the USEPA Secondary Maximum Contaminant Levels (SMCL). SMCLs are a measure of non-enforceable guidelines regulating contaminants that may cause cosmetic effects such as skin or tooth discoloration or aesthetic effects such as color, taste, and odor in drinking water. Large TDS concentrations can adversely affect the taste and odor of drinking water, as well as having a negative effect on crop production when used for irrigation and may cause scale buildup in pipes and boilers. High TDS concentrations can negatively affect fish and wildlife.

Other water quality constituents sometimes found in quantities higher than USEPA and WDEQ water quality standards in the Green River Basin include sulfate, chloride, fluoride, iron and manganese. These constituents may affect the taste and appearance of water as well as causing mild to moderate health problems and crop productivity declines. Trace elements and radioactive contaminants were also found in levels higher than USEPA and WDEQ water quality standards in certain areas of several aquifers in the Green River Basin, making some of these aquifers unsuitable for domestic, livestock, irrigation uses, and fish and wildlife.

Contamination of groundwater resources from point sources such as underground storage tank leaks or industrial releases are a concern. Many locations of former underground storage tanks for gasoline, diesel fuel, or oil have experienced past subsurface leaks from the tanks and/or associated underground pipelines into groundwater. Energy development activities have the potential to contaminate the local groundwater resource, such as has apparently occurred with some volatile organic compounds (VOC) detections in some multiple-use water wells located near Pinedale in Sublette County.

In some areas of the Green River Basin, groundwater contamination is natural and related to the elevated concentrations of water quality constituents from natural sources. Examples of naturally occurring contamination include uranium and other radioactive elements present in the Tertiary Formations in the Great Divide Basin and high levels of inorganic constituents like selenium or fluoride.

Figure 4-5 shows an aquifer sensitivity map of the Green River Basin. Higher sensitivity areas are considered to be more susceptible to shallow groundwater contamination due to the increased permeability of these geologic units and also the relatively shallow depth to groundwater in these areas. Contamination released at the ground surface or in the shallow subsurface (such as underground gasoline/diesel storage tanks) is likely to migrate downward from the shallow depth soils/formations to contaminate the shallowest groundwater underlying a site. Groundwater contamination tends to follow the direction of local groundwater flow from a contaminant point source. Groundwater contamination may be sourced from a specific site (point source) or multiple sources (nonpoint sources).

4.4.5 Groundwater Associated with Energy Development

The Atlantic Rim Coalbed Natural Gas (CBNG) development and associated natural gas field development north of Baggs in western Carbon County is underway with up to 1,800 CBNG and 200 conventional natural gas wells planned for construction. Coalbed natural gas development involves pumping groundwater to lower pressures in the target coal beds and allow the desorption and production of the natural gas from the coals. The groundwater pumping due to CBNG development in the eastern Green River Basin is projected to be approximately 11,760 to 21,168 acre-feet per year. The majority of the groundwater that is produced during the Atlantic Rim CBNG development is planned to be re-injected into other subsurface geologic formations. As of December 2007, more than 13,000 groundwater permits had been issued by the Wyoming State Engineer's Office (WSEO) for the Green River Basin. Of this total number, CBNG wells numbered about 7.7 percent or approximately 1,000 wells. CBNG wells permitted by the Wyoming Oil and Gas Conservation Commission (WOGCC) are shown in Figure 4-6. The coal beds of the Mesaverde Group in the eastern Washakie Basin show an area of planned drawdown as part of the Atlantic Rim CBNG development north of Baggs, Wyoming. The Mesaverde coal aquifer is not of drinking water quality and the production water is planned to be re-injected into other formations in the area.

Besides CBNG production, both petroleum (oil and natural gas) and oil shales exist and are potential energy resources in the Green River Basin. The Tensleep Sandstone aquifer in the northeastern Great Divide Basin shows an area of localized drawdown due to petroleum field development in the area. The Tensleep groundwater in this area is not of drinking water quality and contains hydrocarbon compounds.

The projected water quantities required (Available Groundwater Determination, tech. memo, 2010) for developing oil shale resources in the Basin, such as for a 50,000-barrel per day production facility, are estimated as:

Oil shale surface extraction method	13,400-20,100 acre-ft/year
Oil shale underground method	6,800-10,600 acre-ft/year
Oil shale in-situ retorting method	3,000-5,700 acre-ft/year
Oil shale modified in-situ method	5,000-8,000 acre-ft/year

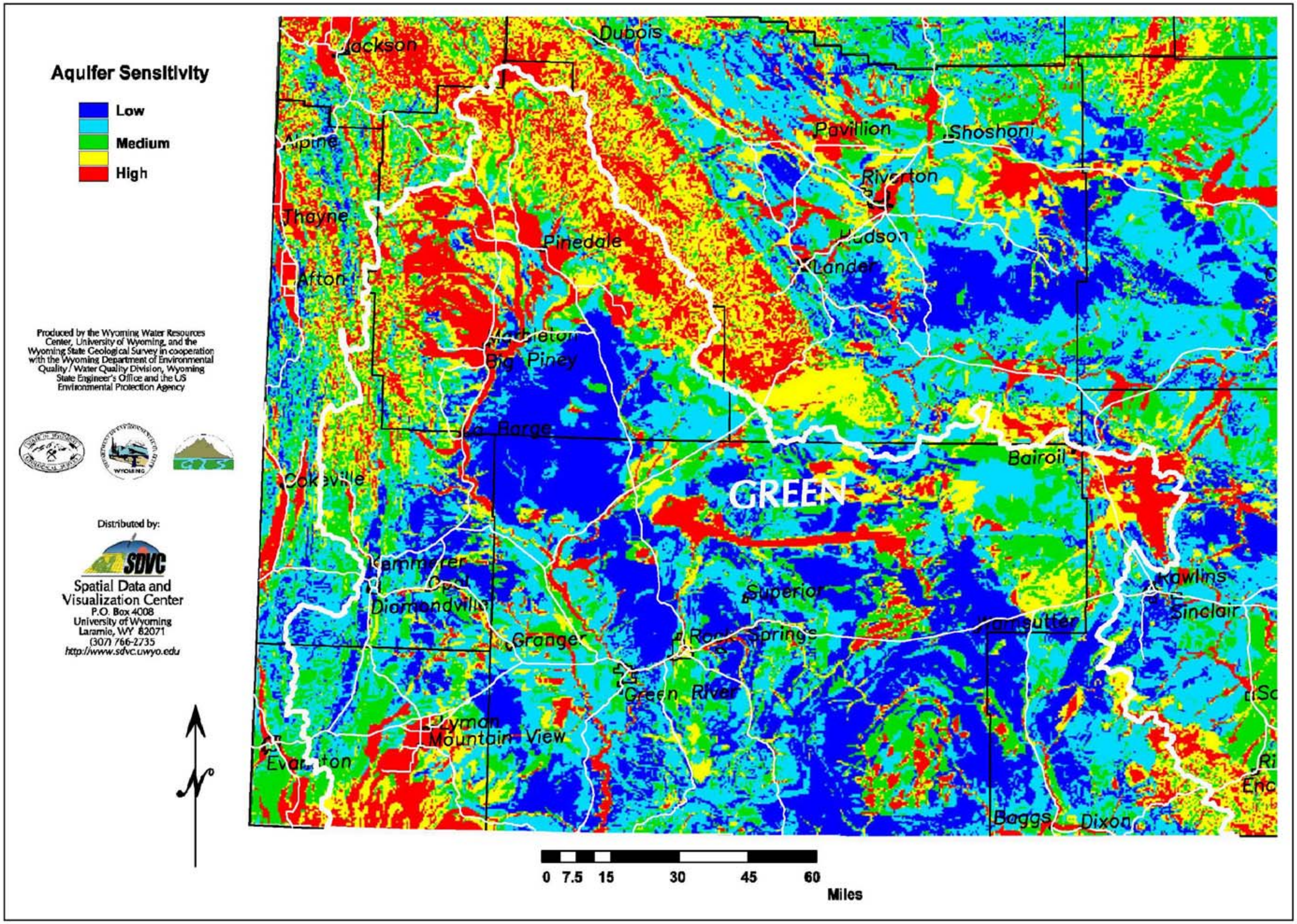
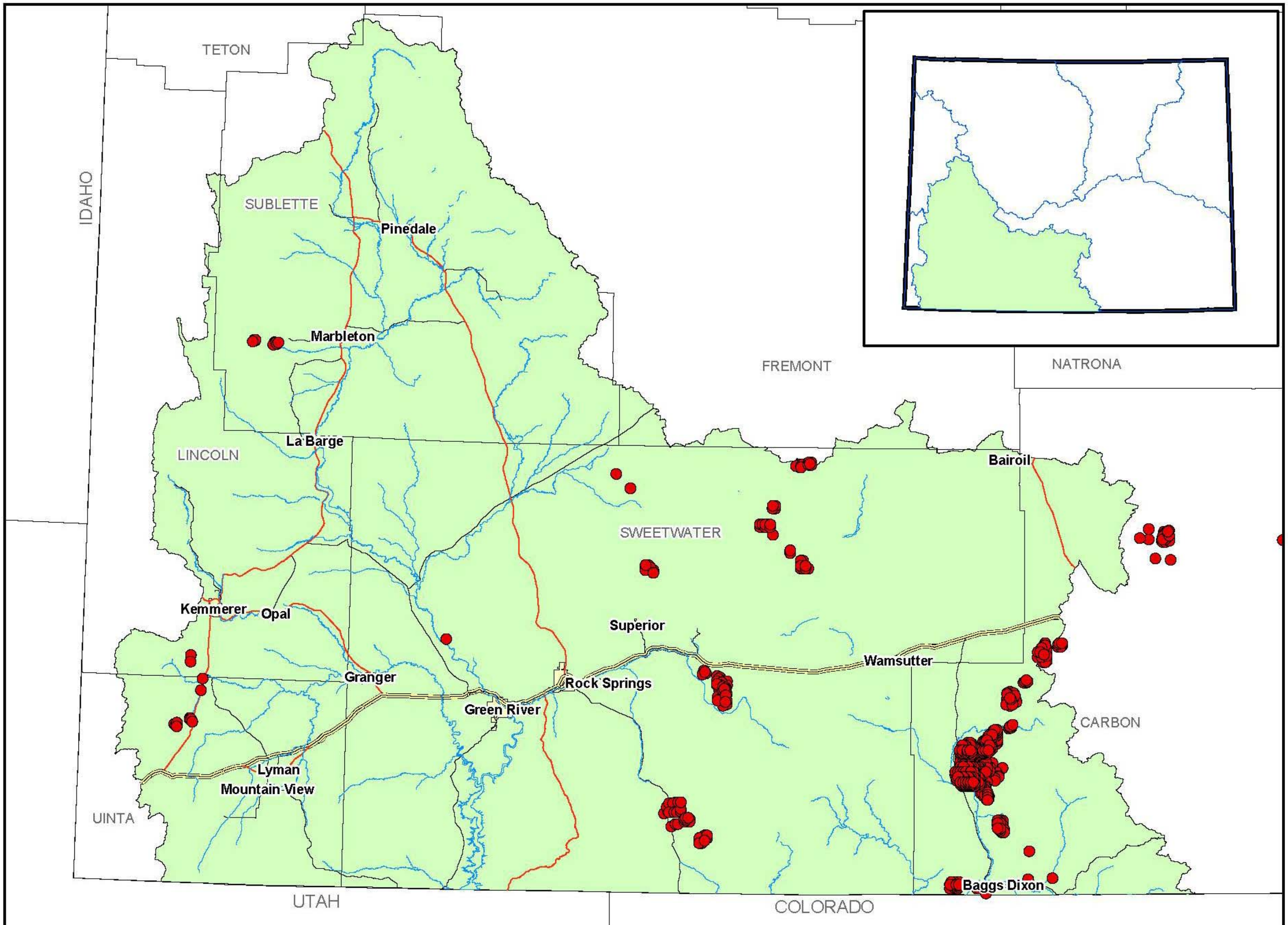


Figure 4-5
Aquifer Sensitivity



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CBNG Well

Source: Wyoming State Engineer''s Office GIS files compiled June 2006.

0 5 10 20 30 40 Miles

N

Figure 4-6
Active CBNG Wells

There is also an interest in developing new underground coal gasification resources in Wyoming. The projected water quantities required (Available Groundwater Determination, tech. memo, 2010) for developing underground coal gasification for a 250-million cubic feet per day production facility are estimated as:

Coal gasification Lurgi process	5,600-9,000 acre-ft/year
Coal gasification synthane process	6,694-10,500 acre-ft/year
Coal gasification synthoil process	9,655-13,000 acre-ft/year

Future energy development of both oil shale and coal gasification resources would require obtaining new water supplies from surface water and groundwater sources in the Green River Basin. Also, both oil shale and underground coal gasification pilot testing have contaminated groundwater resources within the State of Wyoming. The future development of these unconventional energy resources in the Green River Basin will depend on economics, permitting through the WDEQ and adequate pre-project planning to monitor for and remediate any potential groundwater contamination.

4.5 REFERENCES

"Available Groundwater Determination," tech. memo, Clarey, Keith E., Bartos, Timothy, Copeland, David, Hallberg, Laura L., Clark, Melanie L., Thompson, Melissa L. Edited by David Copeland and Meg Ewald, 2010

Leonard Rice Consulting Engineers, 2009. Consumptive use analysis. Draft memo submitted to Wyoming State Engineer's as part of the Wyoming Water rights Attribution Geodatabase Project. 27 June, 2009. 18 pages

"Surface Water Quality," tech. memo, AECOM, 2009

"Green River Basin Climate and Climate Data," tech. memo, AECOM, 2010

"Available Surface Water Determination," tech. memo, AECOM, 2010

"Available Groundwater Determination," tech. memo, Clarey, Keith E., Bartos, Timothy, Copeland, David, Hallberg, Laura L., Clark, Melanie L., Thompson, Melissa L. Edited by David Copeland and Meg Ewald, 2010

Wyoming's Water Quality Assessment and Impaired Waters List (2010 Integrated 305(b) and 303(d) Report)

Water Quality Rules and Regulations, Chapter 8—Quality Standards for Wyoming Groundwaters

5.0 USE

5.1 INTRODUCTION

This chapter presents an inventory of water use and existing water development projects in the Green River Basin. An estimate of consumptive use of water was prepared to compare to compact allotments, to locate places of use relative to water supplies in the Basin, and for water projection estimates. Water use for this report is defined as the total amount of water consumed or lost due to human influence in the Green River Basin. Total Basin water use is divided among the following sectors:

- Agriculture
- Municipal and Domestic
- Industrial
- Recreational
- Environmental
- Evaporation

5.1.1 Colorado River Compacts Administration Program

The Colorado River Compacts Administration Program in the Interstate Streams Division of the State Engineer's Office was created in 2006 with the aim of collecting the data necessary to make water management decisions. Because the program collects high quality water use data, the Program is an excellent resource for water use estimates, especially those pertaining to agricultural water use. The aims of this program include improving the ability to meet the administrative requirements as set out in the Colorado River and Upper Colorado River Basin Compacts and to annually and accurately estimate the quantity of water consumed in the Colorado River Basin (which consists of the Green River and Little Snake River Basins) of Wyoming. These aims are accomplished by the Consumptive Use Determination Plan (CU Plan) funded by the Wyoming Legislature in 2008 that aims to accomplish goals in seven components that are integral in accomplishing the aims of the Colorado River Compacts Administration Program. The seven components are 1) Climate and Hydrology, 2) Diversion and Consumptive Use, 3) Water Rights Attribution, 4) Reservoir Operation, 5) Groundwater, 6) Administration/Decision Support Tools, and 7) Outreach. As the 2008 SEO annual report states, "…the ultimate goal of any action taken under auspices of this CU Plan and the overall Colorado River Compacts Administration Program is to have a clearly defined and defensible approach to the implementation and administration of an Upper Colorado River Basin Commission (UCRBC) initiated curtailment." Although this is a relatively new and ongoing program, many tasks have been accomplished toward achieving goals in all seven components.

5.2 AGRICULTURAL WATER USE

5.2.1 Introduction

Water in the Green River Basin has been used for beneficial agricultural purposes since Territorial days. Agricultural water use, specifically through irrigation, accounts for the vast majority of water consumption in the Green River Basin and the state. This section discusses agricultural water use in the Green River Basin. Leonard Rice Engineers, Inc. recently completed a water rights mapping project for the State Engineer's Office. As part of that project, two products were 1) the Wyoming Water Rights Attribution Geodatabase (WYWRAG), and 2) an irrigated lands consumptive use analysis technical memorandum. The WYWRAG is a ESRI Arcview-based geodatabase of water rights permits, irrigation infrastructure and irrigated lands. The consumptive use memo presents the results of a crop consumptive use analysis for the Green River basin. The consumptive use work (Leonard Rice Engineers, Inc., 2009) provided the majority of information presented in this section.

5.2.2 Agricultural Water Use Methodology

The steps listed below outline the procedure that was used for determining agricultural consumptive use in the Green River Basin:

- Determine irrigated acreage (see Section 5.2.3)
- Identify and document information for key diversion structures, including crop types, irrigation practices, and general operations (5.2.4)
- Determine supply source for irrigated acreage (5.2.5)
- Calculate potential crop consumptive use (evapotranspiration) and consumptive irrigation requirements, and determine effective precipitation (5.2.6)
- Calculate water supply limited or actual crop consumptive use (5.2.7)
- Estimate livestock consumptive use (5.2.8)

The following definitions are for the terms used in this report:

- **Evapotranspiration:** The total amount of water that would be used for crop growth if there was an ample water supply; also called potential consumptive use.
- **Effective Precipitation:** The portion of precipitation that is available to meet the evapotranspiration requirements of the crop (Some precipitation runs off or is evaporated without helping meet the water needs of a crop, and is therefore not effective as used herein).
- **Consumptive Irrigation Requirement (CIR):** The amount of water over and above effective precipitation that is required from a surface or groundwater source to fully meet crop consumptive use. Calculated as evapotranspiration less effective precipitation; also called irrigation water requirement.

- **Supply-Limited Consumptive Use:** The amount of water actually used by the irrigation practice, limited by water availability; also called depletion.

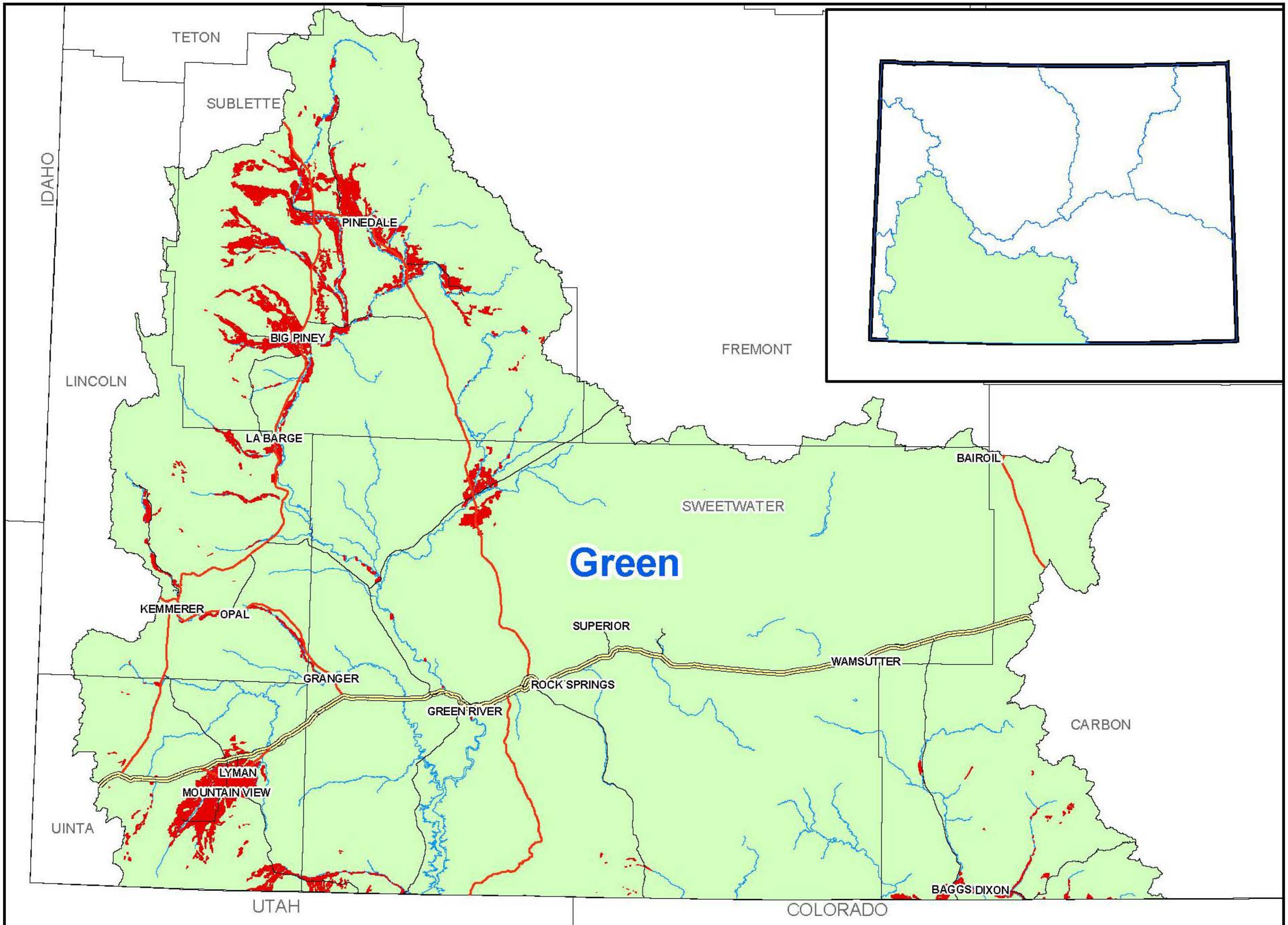
The association of irrigated land with irrigation structures has allowed for more accurate quantification of consumptive use estimates than in previous basin planning efforts; the analysis of crop consumptive use prepared by LRE (Leonard Rice Engineers, Inc. 2009)was performed using StateCU, a generic, data-driven consumptive use model and graphical user interface (GUI) combining climate analysis and an irrigation diversion structure analysis based on water supply-limited actual consumptive use.

5.2.3 Irrigated Acreage

The State Engineer's Office, Wyoming Water Planning Program (WWPP) estimated that there were about 330,000 acres irrigated in the Green River Basin in 1970 (Water & Related Land Resources of the Green River Basin, Wyoming, Report No.3, 1970). The estimate of irrigated acreage developed for the 2001 Green River Basin Plan put the irrigated acreage total at 321,500 acres. This is a slight decrease in irrigation from the 1970 estimate. In this current plan the average total irrigated acreage is reported as 334,500 acres (Leonard Rice Engineers, Inc. 2009). The irrigated acreage numbers from 1970, 2001 and 2009 are very similar. From the higher acreage reported in 2009 to the lower acreage reported in 2001 is a variation of only about 4 percent.

Figure 5-1 shows irrigated lands in the Green River Basin including lands irrigated with surface water and groundwater, man-induced sub irrigation (e.g., lands adjacent to crop lands which may be too wet to farm but which consume water which runs off of croplands during normal irrigation practices), idle lands (i.e., lands under ditch and having valid water rights but not irrigated during the year mapping was done for one or more reasons), and man-made riparian areas (e.g., seepage from dams and canals and irrigation water wasteways).

Table 5-1 shows the irrigated acreage estimates by sub-basin for a representative wet year (based on 1997 imagery), a representative dry year (based on 2002 imagery), and the acreage total from the 2001 Green River Basin Plan. Figure 5-2 presents 4th level hydrologic unit code (HUC-8 sub-basin) sub-basin boundaries, which correspond approximately with the sub-basins in Table 5-1. The average total irrigated acreage is the average of the wet year acreage and dry year acreage, 334,500 acres, which is a 1.2 percent increase over the total in the 1970 Green River Basin Plan. The difference is due in part to the variation in methodology used between the two plans. For the 1970 Green River Basin Plan and the 2001 Green River Basin Plan, water rights were not assigned specifically to irrigated acreage or diversion structures.



Source: Irrigated lands shown are based on GIS coverage developed for 2007 Wyoming Framework Water Plan, which are different than the exact acreages mapped during the SEO Water Rights Attribution Project.

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Irrigated Lands

Figure 5-1
Irrigated Lands

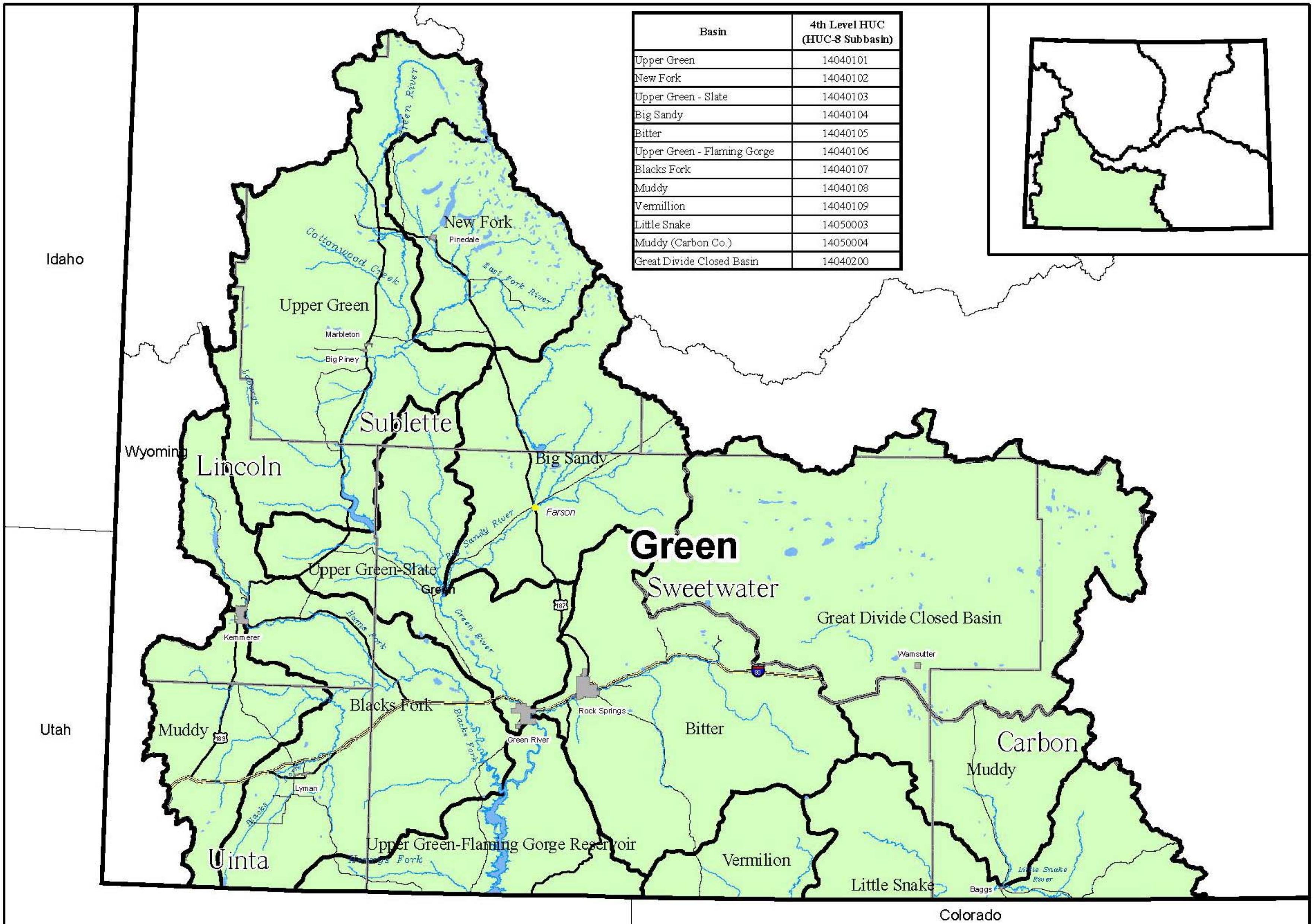
Table 5-1 - Irrigated Acreage by Sub-basin

Sub-basin	Wet Year	Dry Year	2001 GRB Plan
	Acres		
Upper & Mainstem Green River	143,293	126,844	133,372
New Fork	57,900	55,457	52,707
Big/Little Sandy Rivers	19,951	16,241	22,506
Green River Below Fontenelle	1,373	1,097	2,042
Blacks Fork	88,972	63,978	75,173
Hams Fork	12,746	10,811	10,287
Henrys Fork	19,735	15,057	16,690
Little Snake	15,423	14,725	16,959
Vermillion/Salt Wells Creeks	3,180	2,160	674
Total	**362,573**	**306,369**	**330,410**
Average Total Irrigated Acres	**334,500**		**330,410**

Source: Leonard Rice Engineers, Inc. 2009

Notes: Sub-basin names are those used in the source document and commonly used by SEO. They are not the same as HUC-4 sub-basins shown on Figure 5-2.

The irrigated acreage assessment above did not include lands in the Great Divide Basin.



Basin	4th Level HUC (HUC-8 Subbasin)
Upper Green	14040101
New Fork	14040102
Upper Green - Slate	14040103
Big Sandy	14040104
Bitter	14040105
Upper Green - Flaming Gorge	14040106
Blacks Fork	14040107
Muddy	14040108
Vermillion	14040109
Little Snake	14050003
Muddy (Carbon Co.)	14050004
Great Divide Closed Basin	14040200

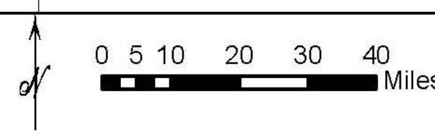


Figure 5-2
Green River Basin Sub-basins

5.2.4 Irrigated Crops

A part of estimating the amount of water used for irrigation is the irrigated crop distribution. Crop evapotranspiration (ET), consumptive irrigation requirements (CIR), and irrigation methods vary by crop type. An accurate assessment of crop distribution is important in the modeling of consumptive uses and in valuing the agricultural sector dependent on those crops.

Grass hay and alfalfa are the main crops in the Green River Basin and were the two crop types used in this analysis (Leonard Rice Engineers, Inc. 2009). Small grains and cash crops are very limited; in the entire Basin only the southwestern Green River Basin produced anything besides grass hay and alfalfa. Table 5-2 lists the percentage of acreage used for grass hay and alfalfa in each water district within Water Division IV. Figure 5-3 presents the water district boundaries for the Basin and also lists diversion structures within each district.

5.2.5 Diversions

Surface Water

Diversion records throughout the Green River Basin are sparse. For this Green River Basin Plan update, 23 structures were identified where the majority of monthly diversions have been recorded since the early 1980s (Leonard Rice Engineers, Inc. 2009). Missing diversion records were extrapolated using pattern gages by assigning explicit structures to a gage and filling in data gaps with the average of available months for the wet, normal, or dry hydrologic condition identified for the missing year. Table 5-3 lists the average monthly diversions during the irrigation season for the 23 structures with diversion records and identifies the pattern gages used for filling in missing data.

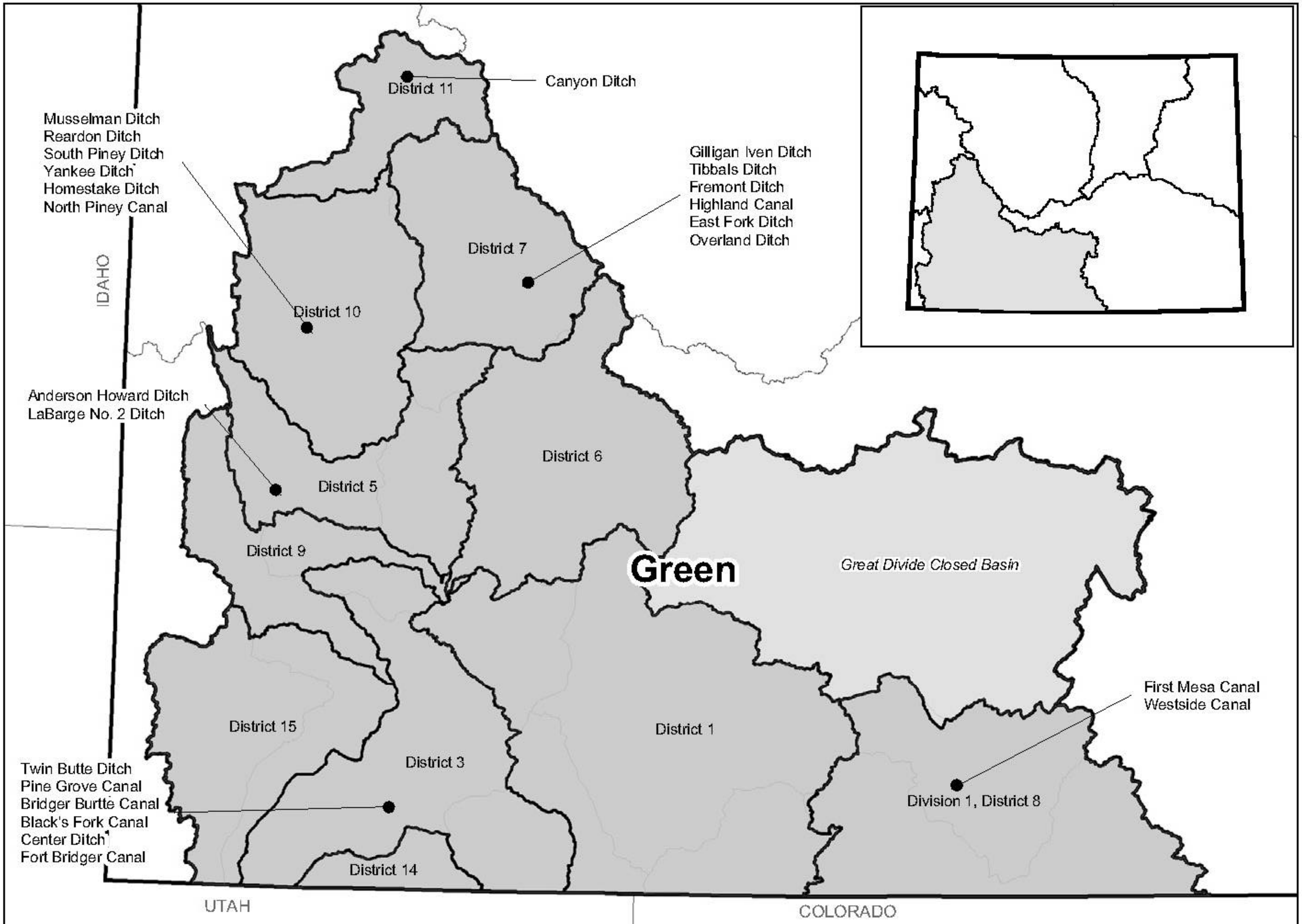
Groundwater

As of December 2007 there were 2,872 wells with permits for agricultural use in the Green River Basin including 115 irrigation wells and 2,757 stock wells; Figure 5-4 shows the locations of active irrigation wells in the Green River Basin. Agricultural use of groundwater includes both irrigation and livestock watering (stock) wells and developed springs. Irrigation use of groundwater in the Green River Basin is estimated at 7,800 acre-feet per year.

Table 5-2 - Crop Types by Water District

Water District	Grass Hay and Pasture	Alfalfa
1	100%	0%
3	96%	4%
5	100%	0%
6	71%	29%
7	100%	0%
8	89%	11%
9	95%	5%
10	95%	5%
11	95%	5%
14	100%	0%
15	90%	10%

Source: Leonard Rice Engineers, Inc. 2009
Note: See Figure 5-3



Map Adapted From Leonard Rice Engineers, Inc. 2009, Figure 1

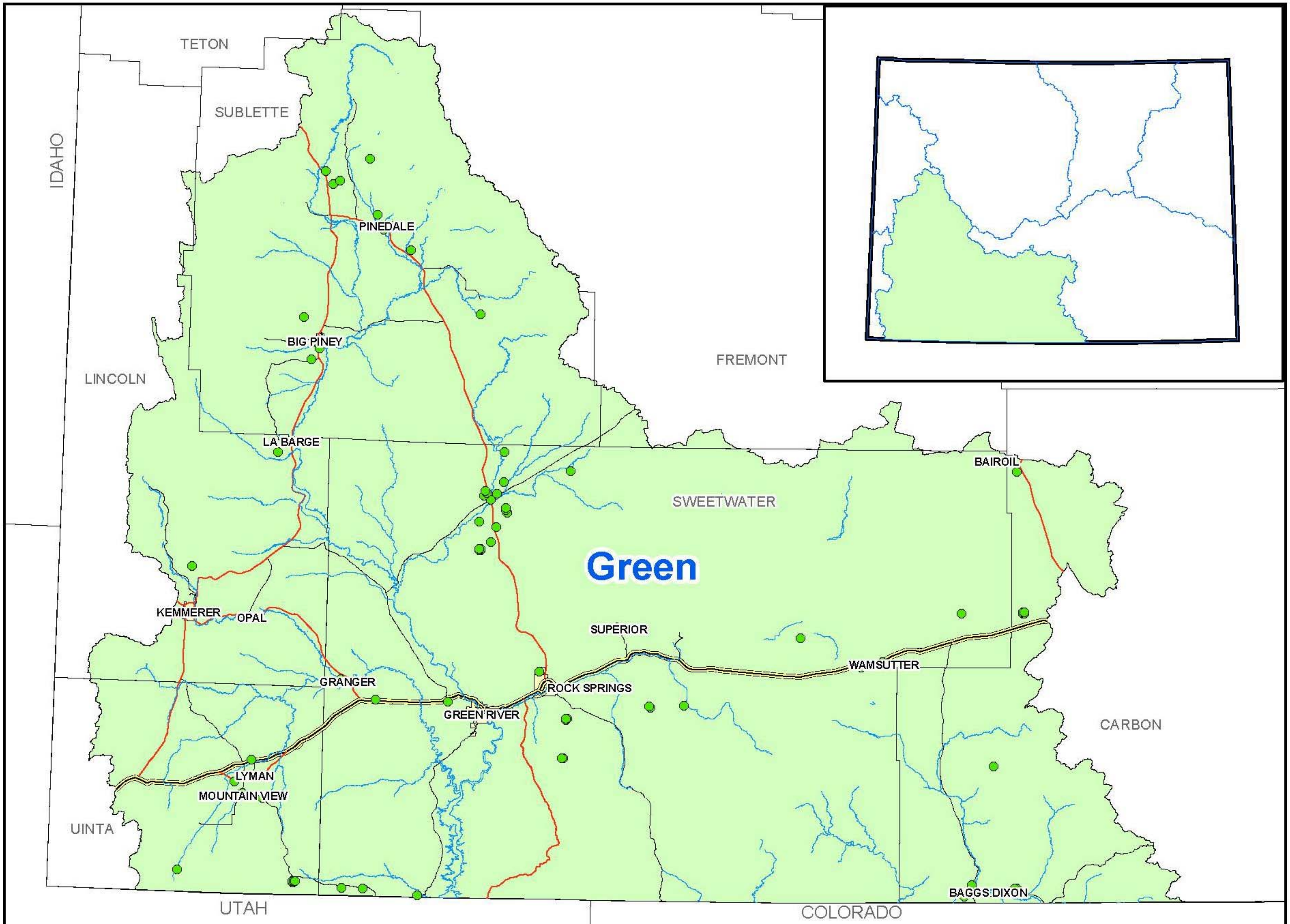
Figure 5-3
Water District Boundaries and Explicit Structure Assignments

Table 5-3 - Average Monthly Diversions and Pattern Gage Assignments

Model ID	Structure Name	Pattern Gage Assignment	April	May	June	July	Aug	Sept	Total
			Acre-feet						
5005005	Anderson & Howard Canal	9210500	274	1,768	3,166	2,234	1,076	333	8,851
5005085	La Barge No. 2 Ditch	9210500	239	1,144	1,153	733	555	165	3,989
7000188	East Fork Canal	9196500	0	792	1,462	780	304	129	3,467
7000223	Fremont Ditch (Pine Creek)	9196500	0	392	1,258	1,283	448	289	3,671
7000237	Gilligan & Iven Ditch	9196500	0	607	866	580	258	123	2,435
7000293	Highland Canal	9196500	0	3,531	9,966	7,454	2,393	1,948	25,292
7000663	Tibbals Ditch	9196500	0	1,104	1,585	994	569	532	4,784
7154143	Overland Ditch (East Fk River)	9196500	0	1,392	2,144	1,453	197	94	5,280
8000215	First Mesa Canal	9523000	0	3,838	5,170	3,202	1,611	1,357	15,178
8153666	West Side Canal	9523000	0	5,419	8,890	4,770	2,049	1,509	22,638
10000301	Homestake Ditch	9188500	307	1,255	2,388	1,623	593	270	6,436
10000471	Musselman Ditch (District 10)	9188500	0	464	791	407	166	98	1,926
10000610	South Piney Ditch	9188500	35	758	2,015	1,169	272	54	4,302
10000715	Yankee Ditch	9188500	82	410	737	587	495	242	2,553
10000917	Reardon Ditch	9188500	256	1,344	1,990	1,178	408	192	5,368
10000943	North Piney Ditch	9188500	50	852	1,742	1,223	712	429	5,007
11000124	Canyon Ditch (Green River)	9188500	0	1,306	2,692	3,190	1,847	801	9,836
15153041	Black's Fork Canal	9218500	0	7,535	13,440	9,293	4,162	3,666	38,096
15153048	Bridger Butte Canal	9218500	198	1,648	2,615	1,213	265	423	6,362
15153084	Center Ditch	9218500	54	198	490	242	141	145	1,269
15153153	Fort Bridger Canal	9218500	189	1,424	2,203	1,540	895	850	7,100
15153348	Pine Grove Canal	9218500	162	2,659	4,520	2,740	567	533	11,182
15153440	Twin Butte Ditch (District 15)	9218500	161	975	1,792	1,352	489	471	5,240

Source: Leonard Rice Engineers, Inc. 2009

Note: Monthly diversion records for 23 structures were compiled and extended. The majority of the explicit structures had monthly diversion recorded starting in the 1980s. Missing diversion records were estimated using the pattern gage approach where the characteristics of an explicit gage are used to estimate missing records. See Leonard Rice Engineers, Inc. 2009 and its supporting documentation for a more complete description of methods.



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Active Irrigation Well

Source: Wyoming State Engineer's Office GIS files compiled June 2006

Figure 5-4
Active Irrigation Wells

Theoretical Maximum Diversion Requirement

Not all of the water diverted for irrigation goes to meeting the CIR; in fact the CIR can represent less than half of the total diversion amount. A significant portion of the diverted flow is lost to seepage from the conveyance ditch, lateral ditches, and field ditches; headgate leakage; evaporation losses from sprinklers; ditch tailwater waste; field runoff; and deep percolation past the crop root zone. The proportion of water ultimately consumed by the crop compared to the total volume of water diverted from the stream is referred to as overall efficiency. Using estimated overall irrigation efficiency, one can calculate the theoretical maximum diversion requirement from the theoretical CIR. Irrigation efficiency typically varies throughout the irrigation season but decreases as the amount of water applied relative to the crop irrigation requirement increases. For example, overall efficiency would typically be at a minimum during the early irrigation season when water supply is abundant but crop water requirements are minimal. Conversely, overall efficiency would typically be at a maximum during the summer months (July and August) when water supply is limited, soil moisture is depleted, and crop water requirements are at a maximum.

As noted previously, 23 structures were identified as having sufficient diversion records to enable determination of actual or supply-limited consumptive use (Leonard Rice Engineers, Inc. 2009). These 23 structures were used as a basis for estimates of consumptive use for the structures without sufficient diversion records. Conveyance efficiency is applied to headgate diversions to determine the amount of water delivered to the farm. Table 5-4 lists conveyance efficiency for explicit source structures.

Application efficiency (or on-farm efficiency) is the ratio between the crop consumptive use and the amount of water applied to the lands, whether by sprinklers, flood irrigation or other application method. The water supply-limited analysis caps application efficiency at a standard maximum and allows application efficiency to vary up to that maximum based on water supply. Maximum flood application efficiency was assumed to be 60 percent and maximum sprinkler acreage efficiency was assumed to be 80 percent based on standard references.

5.2.6 Consumptive Use Requirement

This section summarizes how consumptive use requirement of crops was estimated (Leonard Rice Engineers, Inc. 2009). The consumptive use of a crop for a given area depends on growth stage, water availability, and climate factors such as temperature, humidity, solar radiation, and wind speed.

The CIR is estimated by subtracting effective precipitation from evapotranspiration. Alfalfa and grass hay require the most water and thus

Table 5-4 - Explicit Structure Conveyance Efficiencies

Water District	Model ID	Structure Name	Conveyance Efficiency
3	15153348	Pine Grove Canal	80%
5	5005005	Anderson & Howard Canal	90%
5	5005085	La Barge No. 2 Ditch	80%
7	7000237	Gilligan & Iven Ditch	80%
7	7000663	Tibbals Ditch	90%
7	7000223	Fremont Ditch (Pine Creek)	90%
7	7000293	Highland Canal	60%
7	7000188	East Fork Canal	60%
7	7154143	Overland Ditch (East Fork River)	90%
8	8000215	First Mesa Canal	90%
08**	8153666	West Side Canal	75%
10	10000471	Musselman Ditch (District 10)	90%
10	10000917	Reardon Ditch	90%
10	10000610	South Piney Ditch	90%
10	10000715	Yankee Ditch	75%
10	10000301	Homestake Ditch	90%
10	10000943	North Piney Ditch	90%
11	11000124	Canyon Ditch (Green River)	90%
15	15153041	Black's Fork Canal	80%
15	15153048	Bridger Butte Canal	90%
15	15153440	Twin Butte Ditch (District 15)	90%
15*	15153084	Center Ditch	100%
15*	15153153	Fort Bridger Canal	100%

*These ditches gain water en route to irrigated lands from upstream ditch leakage. (SWWRC 2001)

**West Side efficiency estimated as having significant seepage
Source: Leonard Rice Engineers, Inc. 2009

have the highest CIRs of the crops grown in the Basin, while small grains and beans use much less water. Table 5-5 shows CIR and actual consumptive use (CU) for wet and dry year scenarios.

For this report the modified Blaney-Criddle method with the high-altitude elevation adjustment recommended in ASCE Manual 70 was used to estimate CIR (Leonard Rice Engineers, Inc. 2009). The method generates CIR estimates based on local climate data and reflect monthly and annual climate variations, address the effects of high altitude, and can be easily reproduced and updated. The elevation adjustment recognizes that the modified crop coefficients were developed at lower elevations that do not experience the large variation between day-time and night-time temperatures that occur in the higher elevations of Wyoming.

Table 5-5 - Average Annual Basin Results (1971-2007) for Representative Wet and Dry Year Acreage

	Water District	CIR	Actual CU	Percent Short
		(Acre-Feet)		
WET YEAR	1	5,879	5,655	4%
	3	53,142	41,898	21%
	5	16,804	16,558	1%
	6	27,656	27,656	0%
	7	63,546	63,073	1%
	8	30,407	29,096	4%
	9	16,940	16,641	2%
	10	133,172	113,629	15%
	11	20,527	20,527	0%
	14	33,795	26,482	22%
	15	84,663	60,424	29%
	Total	**486,531**	**421,639**	**13%**
DRY YEAR	1	3,993	3,840	4%
	3	35,462	30,010	15%
	5	15,162	15,044	1%
	6	22,514	22,514	0%
	7	60,865	60,496	1%
	8	29,398	28,097	4%
	9	14,368	14,222	1%
	10	118,455	106,650	10%
	11	17,260	17,260	0%
	14	25,784	21,677	16%
	15	63,645	51,044	20%
	Total	**406,905**	**370,852**	**9%**
Average		**446,718**	**396,246**	**11%**

Source: Leonard Rice Engineers, Inc. 2009

5.2.7 Water Supply-Limited Consumptive Use of Crops

The CIR is an estimate of how much water crops could use given a full or ideal water supply, but crops are often grown with less. Water availability, timing, canal capacity, efficiency, and labor availability/costs are some reasons crops receive less than a full supply. Adjustments were made to the ideal CIR to account for years when water supply is not sufficient to provide a full water supply in the Basin. Table 5-6 shows the total water supply-limited consumptive use (the amount of water actually consumed by crops) and provides a comparison to the consumptive use estimated in the 2001 Green River Basin Plan. Estimates of water supply-limited consumptive use are generally similar to those in the 1970 or 2001 Green River Basin Plan.

Table 5-6 - Estimated Agricultural Depletion Green River Basin Plan I 2001 versus Green River Basin Plan 2010

Sub-basin	GRBP II 2010 Consumptive Use	GRBP I 2001 Consumptive Use	Percent Difference
	(Acre-Feet)		
Upper & Mainstem Green River	144,833	152,383	-5%
New Fork	61,784	60,911	1%
Big/Little Sandy Rivers	25,085	36,164	-44%
Blacks Fork	91,688	93,609	-2%
Hams Fork	15,431	12,772	17%
Henrys Fork	24,079	20,658	14%
Little Snake	28,596	20,517	28%
Vermillion/Salt Wells Creeks	4,748	4,023	15%
Total	**396,246**	**401,037**	**-1%**

Source: Leonard Rice Engineers, Inc. 2009

5.2.8 Livestock Consumptive Use

Livestock growing is the dominant agricultural enterprise in the Green River Basin and due to the long winters and relatively short growing season, large amounts of grass hay and alfalfa are grown in the area.

Livestock consumption estimates are based on ten gallons of water per cow per day and four gallons of water per sheep per day. In 2005 the estimated livestock consumptive use was 1,755 acre-feet of water per year.

5.3 MUNICIPAL AND DOMESTIC WATER USE

5.3.1 Introduction

Municipal and domestic uses are a relatively small but important part of the overall water use in the Green River Basin. Municipal water uses are satisfied by public water supply systems, which are served by surface water, groundwater, or combinations thereof.

Domestic water use includes use by rural homes, most of which are served by individual groundwater wells permitted for domestic use and public water supply systems that serve rural subdivisions, commercial establishments, parks, campgrounds and other smaller uses. These small establishments generally have their own water supplies and are not hooked up to municipal and industrial water supply systems; they are almost exclusively supplied by groundwater.

Municipal and domestic use is directly proportional to population. The best population numbers for the Basin at the time this report was prepared were the 2005 estimates prepared by the WDAI Economic Analysis Division, which estimates are GIS based census estimates.

5.3.2 Current Municipal and Domestic Water Use

The purpose of this section is to provide current water use information for the fourteen (14) Green River Basin cities, towns, and joint power water boards (JPB) that supply water to their citizens or customers.

Entities that obtain their primary water supply from surface water and their surface water sources are:

- Town of Baggs – Little Snake River
- Bridger Valley Joint Powers Board – Smiths Fork and Blacks Fork Rivers
- Town of Dixon – Little Snake River
- Town of Granger – Green River
- Kemmerer-Diamondville Joint Powers Water Board – Hams Fork River
- Town of LaBarge – Green River
- Town of Pinedale – Fremont Lake Dam
- Green River/Rock Springs/Sweetwater County Joint Powers Water Board – Green River

Entities that obtain their primary water supply from groundwater (and the source aquifer) are:

- Town of Bairoil (Battle Springs Formation)
- Town of Big Piney (Wasatch Formation)
- Town of Marbleton (Wasatch Formation)
- Town of Opal (Green River Formation)
- Town of Superior (Erickson Sandstone)
- Town of Wamsutter (Wasatch Formation)

One out-of-basin entity, the City of Cheyenne, obtains a portion of its municipal water from the North Platte River system and replaces it with water from the Little Snake River system. This is because of restrictions on water uses from the North Platte River imposed by court decree. Diversions by the city of Cheyenne from the Little Snake River to the North Platte River are not included as a Green River Basin municipal water use but are included in this report as a separate category of water use.

Table 5-7 shows the current municipal and domestic water use for the Green River Basin in acre-feet per year. Information was obtained from the various municipalities through direct communication or from the municipalities' responses to the WWDC's 1999, 2004, 2007, and 2008 "*Water System Survey Reports.*" Populations served by municipal systems were subtracted from total county populations within the Green River Basin to estimate the rural population served by individual domestic water systems.

Table 5-7 - Municipal and Domestic Water Use in 2005

	Municipal		Domestic	
	Surface Water	Groundwater	Surface Water	Groundwater
	Acre-Feet/Year			
2005 Use	6,578	884	≈0	2,027
Total	**7,462**		**2,027**	

Note: 2005 was selected as the base year as that was the most recent accurate hydrologic basin population number for the 5 county area encompassing the Green River Basin at the time this report was compiled. WWDC 2007 per capita use, *State of Wyoming 2007 Water System Survey Report* was applied to the estimated 2005 population to estimate total water use.

Municipal Water Use

Municipalities often provide water to customers within and outside their corporate limits. Some of the municipalities or joint powers water boards also sell water to surrounding water districts; water sales outside the corporate limits for domestic use are included in municipal water use estimates for this report. In addition, municipalities may sell water to industrial water users; these water sales are considered industrial water uses for this report.

Municipal surface water use has increased less than 1 percent since 2001. Table 5-8 summarizes the surface water use for the eight (8) municipal surface water suppliers in the Green River Basin for the year 2005. The Green River/ Rock Springs/ Sweetwater County Joint Powers Water Board supplies over 75 percent of municipal water in the Basin.

Municipal groundwater use in the Green River Basin is considered to have no impact on surface water flows due to the depth of the wells. Table 5-9 shows municipal groundwater use in 2005. Groundwater use has increased by 9 percent since 2001. Figure 5-5 shows municipal wells in the Green River Basin.

The largest Green River system municipal water user is not located in the Green River Basin. The City of Cheyenne diverted an average of approximately 15,300 acre-feet of water per year from the Little Snake River Basin to the North Platte River Basin in the period 2003 through 2007. The 14 water suppliers located in the Green River Basin deplete approximately 7,462 acre-feet of water per year, about half of Cheyenne's diversion. Cheyenne's diversions out of basin have increased by 6.4 percent since 2001 but have not reached the maximum allowed by their water rights. Cheyenne's potential yield from the Little Snake River system is 21,000 acre-feet per year in normal and wet years and about 16,400 acre-feet per year in drought conditions. Table 5-10 shows diversions for the City of Cheyenne from the 2001 Green River Basin Plan and the current Green River Basin Plan.

Table 5-8 - Green River Basin 2005 Municipal Surface Water Depletions in Acre-Feet

City/Town	Population[1]	GPCPD[2,3]	River	Jan.	Feb.	Mar.	Apr.	May
Baggs	354	70	Little Snake	2.8	2.5	2.2	0.3	0.3
BV JPB[4]	4,500	83	Smith/Black	16.7	16.7	16.7	20.9	29.3
Dixon	81	279	Little Snake	1.5	1.5	1.5	1.5	1.8
Granger	146	120	Green	0.2	0.2	0.2	0.4	4.5
K/D JPB[5]	3,950	68	Hams Fork	12.0	12.0	12.0	9.0	21.1
LaBarge	421	313.5	Green	7.4	5.9	5.9	5.9	11.8
Pinedale	1,800	288	Fremont Lk	23.2	5.8	11.6	29.0	46.5
GR/RS/SC[6]	35,000	129	Green	151.7	151.7	151.7	151.7	505.7
Total	**46,252**	**127**		**215.6**	**196.4**	**202.0**	**218.8**	**620.9**
City/Town	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Total**
Baggs	1.1	5.0	3.9	3.1	2.2	2.2	2.8	27.8
BV JPB[4]	37.7	100.4	62.8	50.2	25.1	25.1	16.7	418.4
Dixon	3.0	4.1	3.0	2.5	1.8	1.8	1.5	25.3
Granger	9.8	1.6	1.2	0.6	0.4	0.2	0.4	19.6
K/D JPB[5]	36.1	75.2	57.2	27.1	12.0	12.0	15.0	300.9
LaBarge	17.7	29.6	22.2	13.3	7.4	5.9	10.3	147.8
Pinedale	23.2	116.1	121.9	81.3	69.7	23.2	34.8	580.7
GR/RS/SC[6]	758.6	1062.1	910.3	556.3	252.9	252.9	252.9	5057.4
Total	**887.3**	**1394.0**	1182.5	**734.4**	**371.5**	**323.3**	**334.5**	**6577.9**

Source: WWC Engineering, 2009 (G)

[1]Population is WDA&I or service area estimated population as appropriate.

[2]Gallons per capita per day(GPCPD) are from the State of Wyoming 2007 Water System Survey Report.

[3]GPCPD in the Total row is calculated from the total water use divided by the total municipal populations.

[4]BV JPB-Bridger Valley Joint Powers Water Board .

[5]K/D JPB-Kemmerer-Diamondville Joint Powers Water Board

[6]GR/RS/SC-Green River, Rock Springs, Sweetwater County Joint Powers Water Board.

Note: 2005 was selected as the base year as that was the most recent accurate hydrologic basin population number for the 5 county area encompassing the Green River Basin at the time this report was compiled. WWDC 2007 per capita use, *State of Wyoming 2007 Water System Survey Report* was applied to the estimated 2005 population numbers.

Table 5-9 - 2005 Green River Basin Municipal Groundwater Uses

City/Town	Wells	Depth	Population[1]	GPCPD[2,3]	Total
		Feet			Acre-Feet/Year
Bairoil	5	35-51	96	350	38
Big Piney	7	90-900	455	90	46
Marbleton	8	580-830	811	787	715
Opal	3	400-480	99	150	17
Superior	3	1700	239	146	39
Wamsutter	3	1,365-1,905	265	100	30
Total	**29**		**1965**	**402**	**884**

Source: WWC Engineering, 2009 (G)

[1] Population is WDA&I estimates for 2005.

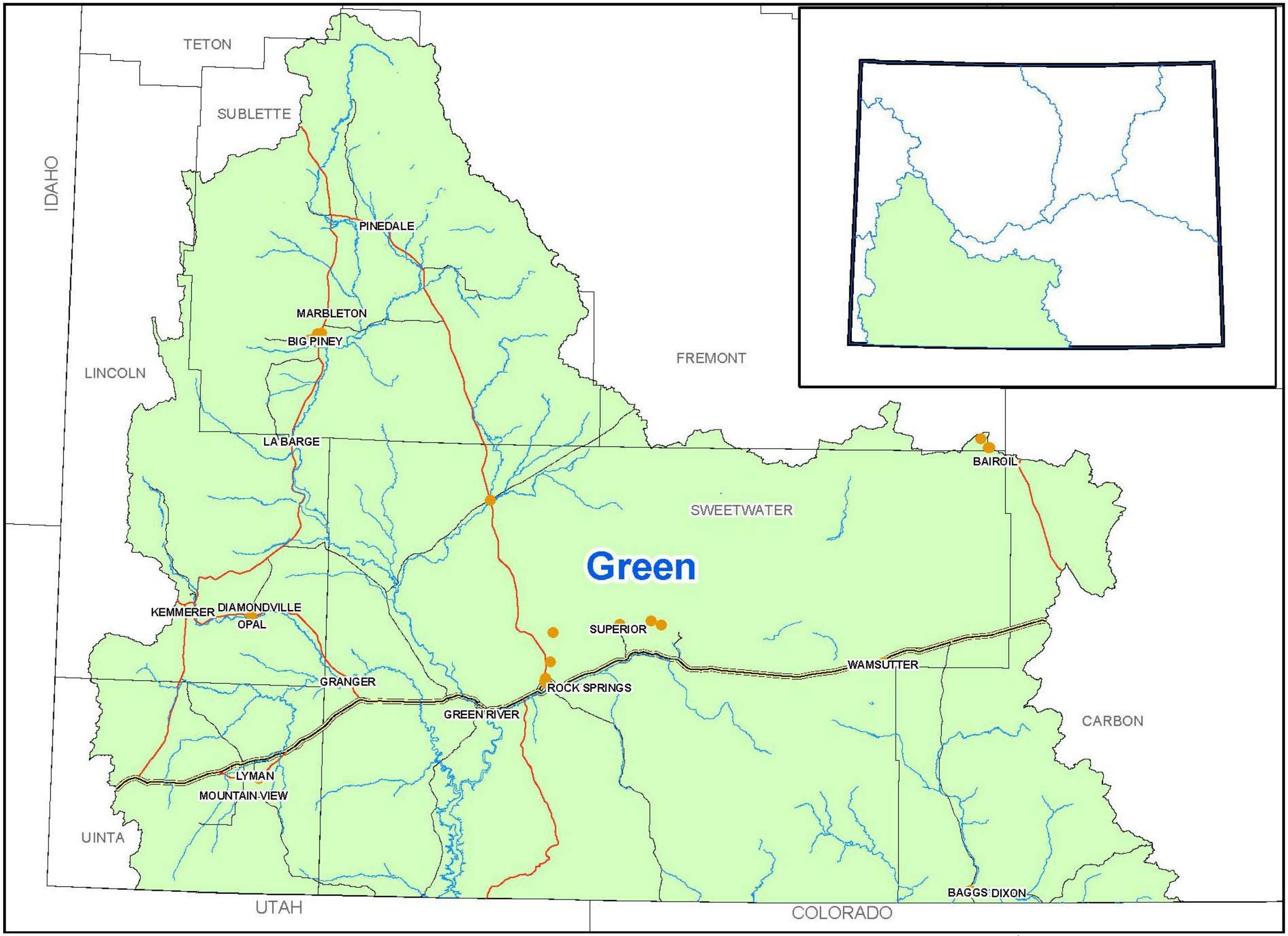
[2]Gallons per capita per day (GPCPD) are from the WWDC 2007 Water System Survey Report.
[3]GPCPD in the Total row is calculated from the total water use divided by the total municipal population.

Note: 2005 was selected as the base year as that was the most recent accurate hydrologic basin population number for the 5 county area encompassing the Green River Basin at the time this report was compiled. WWDC 2007 per capita use, *State of Wyoming 2007 Water System Survey Report* was applied to the estimated 2005 population.

Table 5-10 - City of Cheyenne Diversions Municipal Surface Water Export Comparison

Month	Period	
	1995-1997[1]	2003-2007[2]
	Acre-Feet	
January	22	0
February	8	0
March	6	7
April	145	570
May	4,132	7,685
June	9,683	6,853
July	372	166
August	12	0
September	4	0
October	2	0
November	1	0
December	1	0
Total	**14,388**	**15,281**

Source: [1]Purcell Consulting Technical Memorandum,Green River Basin Plan, Basin Water Use Profile - Municipal, 2001
[2]Cheyenne Board of Public Utilities, phone conversation, May 2008



LEGEND

Municipal Well

Source: Wyoming State Engineer's Office GIS files compiled June 2006. All wells with municipal use in the water right were included.

Figure 5-5
Municipal Wells

Table 5-11 provides a comparison of reported peak day demand with the reported system capacity, the capacity of the direct flow, and storage water rights for the 14 suppliers in the Green River Basin. The information in the table indicates that the water suppliers have sufficient system and water right capacity to meet their existing demands, as well as the opportunity to meet the demands of some future growth. However, the suppliers may have other water supply problems in the form of system rehabilitation needs. Further, simply having water rights does not necessarily mean those water rights can meet the demands in drought years; there must be water available at the points of diversion and the water rights must have priority dates that can withstand water rights regulation in times of shortage.

Domestic Water Use

Existing county populations within the Green River Basin are used as the basis for estimating domestic water use. A population of approximately 9,866 are served by wells permitted for domestic use. If it is assumed that this population consumes between 150 and 300 gallons per capita per day, the resulting estimated domestic water use from these domestic wells would range between 2,028 and 4,065 acre-feet per year. Table 5-12 shows domestic use and Figure 5-6 shows domestic wells in the Basin.

5.4 INDUSTRIAL WATER USE

5.4.1 Introduction

Industry is a major user of water in the Green River Basin. Industries that obtain their primary water supply from surface water sources are electric power generation, soda ash production, and miscellaneous smaller users. The industries that obtain their primary water supply from groundwater are coal mining, uranium mining and the oil and gas industries.

5.4.2 Current Water Use

The industries that obtain their primary water supply from surface water and their water sources are:

Electric Power Generation

- Jim Bridger Power Plant (PacifiCorp) – Green River
- Naughton Power Plant (PacifiCorp) – Hams Fork River

Soda Ash Production and Related Products

- FMC Wyoming – Green River
- General Chemical – Green River
- OCI Wyoming – Green River
- Solvay Minerals Inc – Green River
- Church and Dwight (baking soda production) – Green River

Table 5-11 - Comparison of Municipal Use and System Capacity in 2007

Supplier	Peak Day Demand	System Capacity	Water Right Capacity (GW or Direct Flow)	Storage Rights
	AFD= Acre-Feet Per Day			Acre-Feet
Baggs	0.68	1.33	1.24	None
Bairoil	0.77	3.05	0.41	None
Big Piney	0.41	2.65	3.76	None
Bridger Valley JPB[1]	6.60	12.10	15.56	1,500
Dixon	0.08	0.97	0.97	None
Granger	0.31	3.09	13.01	None
GR/RS/SC JPB[2]	70.58	97.00	79.30	None
K/D JPB[3]	6.14	12.83	17.07	1,770
LaBarge	1.54	1.77	2.64	None
Marbleton	2.15	2.20	5.40	None
Opal	0.06	0.41	0.46	None
Pinedale	9.21	44.20	11.48	17,439
Superior	0.28	1.60	3.36	None
Wamsutter	0.83	3.09	1.51	None

Source: WWC Engineering, 2009 (G)

[1]The Bridger Valley Joint Powers Board has water rights for 1,500 acre-feet of storage in Stateline Reservoir, without the ability to carry over into the following year.

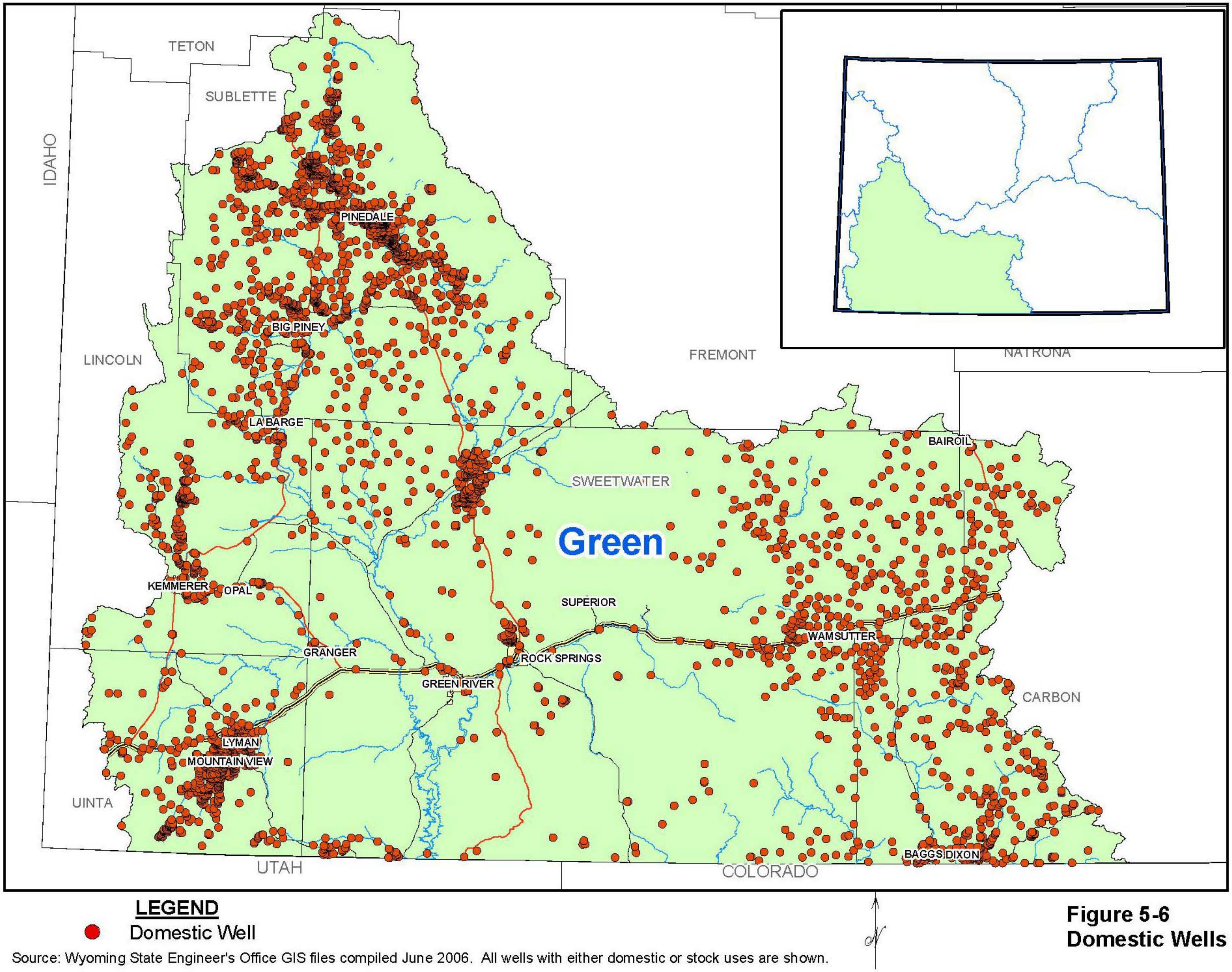
[2]GR/RS/SC-Green River, Rock Springs, Sweetwater County Joint Powers Water Board

[3]K/D JPB-Kemmerer, Diamondville Joint Powers Water Board

Table 5-12 - 2005 Estimated Domestic Use

Supplies	Population	Estimated Use* Acre-Feet/Year
Rural Public Water Supply Systems	2,200	370 - 740
Individual Domestic Wells	9,866	1,658 - 3,316
Total Domestic Use	**12,066**	**2,028 - 4,056**

*Based on the range of 150-300 gallons per capita per day (gpcpd) consumption and 2005 estimated rural basin population.
Source: WWC Engineering, Tech Memo 2009 (H)



LEGEND

Domestic Well

Source: Wyoming State Engineer's Office GIS files compiled June 2006. All wells with either domestic or stock uses are shown.

Figure 5-6
Domestic Wells

Miscellaneous

- Exxon Shute Creek Plant (natural gas processing) – Green River
- Simplot Phosphates (chemical fertilizer production) – Green River

The industries that obtain their primary water supply from groundwater are:

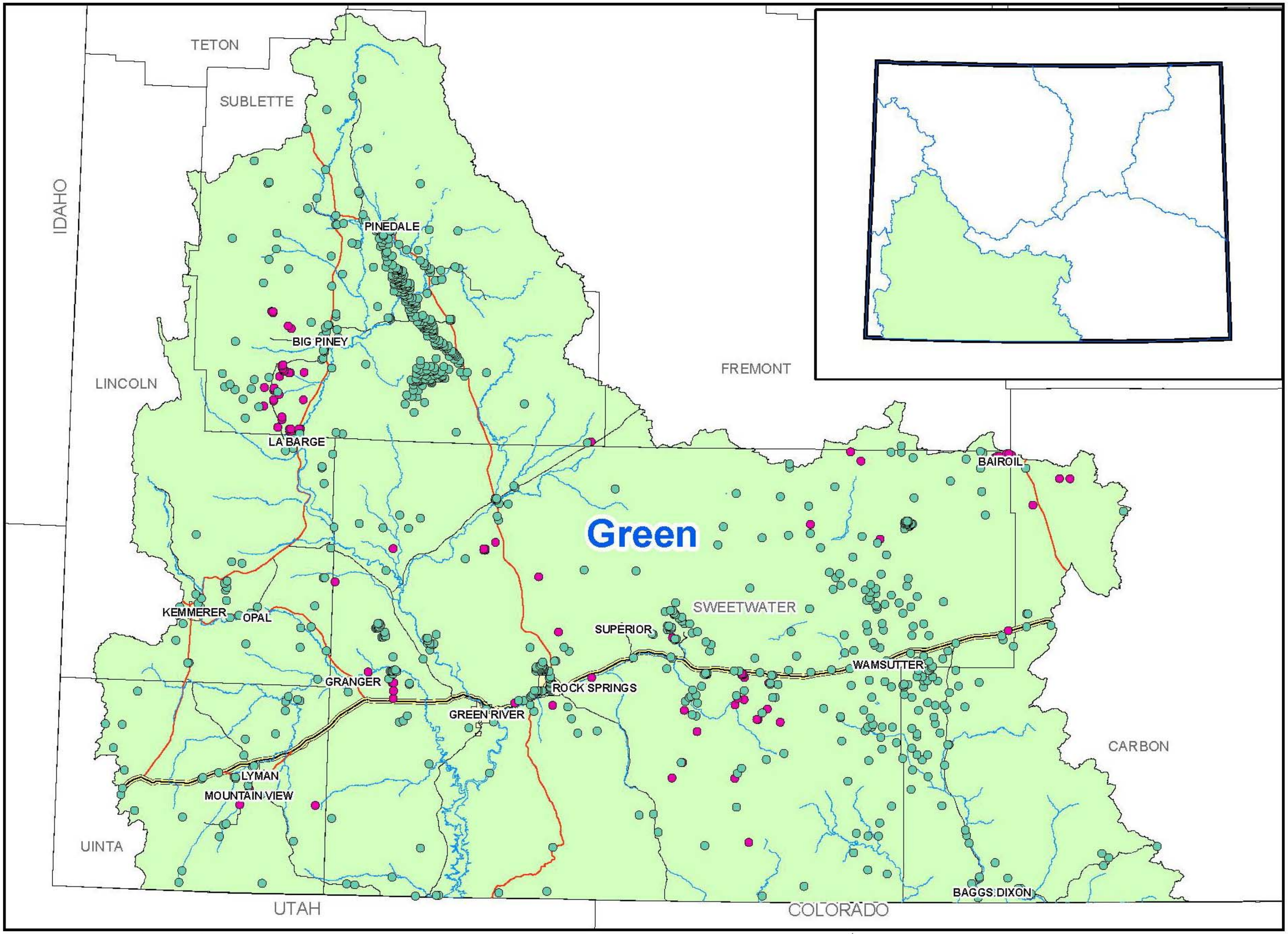
- Coal mining
- Uranium mining
- Oil and gas industries

Information on industrial surface water use was obtained from the various industries primarily through the State Engineer's Office (SEO) Hydrographer's Annual Report or direct communication with industrial users. Information is very limited regarding industrial groundwater use because industries' use of groundwater is typically short-term and intermittent in nature. In addition there is not a requirement to report actual water use on very many SEO permits. The State Engineer's database shows that there are 207 groundwater right permits in the Green River Basin that indicate industrial use on the permit. Figure 5-7 shows industrial and miscellaneous wells.

Surface Water Use

Power plants are the largest industrial water users in the Green River Basin, accounting for approximately 70 percent of industrial water use. The Jim Bridger and Naughton power plants, both owned and operated by PacifiCorp, were estimated to deplete approximately 47,800 acre-feet of water per year in 2000. Based on industry-reported diversions to the SEO, the two power plants depleted approximately 39,700 acre-feet in 2005 – 2006. Both power plants enjoy the security of storage water: PacifiCorp maintains a contract for storage water from Fontenelle Reservoir for use at the Jim Bridger Power Plant during times of severe drought and owns and operates Viva Naughton Reservoir, which serves as the primary supply for the Naughton Power Plant. In both plants, water is used to produce steam for power production and is used in the cooling processes. The majority of the water is evaporated in the cooling towers or lost through evaporation ponds. Some water is used for dust abatement, plant washdown and domestic use.

The soda ash industry consumes over 29 percent of the industrial water used in the Basin. There are four major producers of soda ash in the Green River Basin. FMC Wyoming Corporation, General Chemical Company, OCI Wyoming, and Solvay Minerals, Inc. produced approximately 19.5 million tons of trona in 2005. FMC operates two plants under one management entity, FMC Wyoming, a company consolidated from FMC Granger and FMC Westvaco in 2002. Under 2000 levels of production, these four producers were estimated to deplete approximately 17,900 acre-feet of water from the Green River. Under current levels of production these four producers reported depletions of approximately 16,400 acre-feet of water from the Green River. Water is used in the soda ash production process to dissolve raw trona mineral to remove



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Industrial Well Miscellaneous Well

Source: SEO GIS files compiled June 2006. All wells with industrial and miscellaneous use in the water right were included.

Figure 5-7
Industrial and Miscellaneous Wells

impurities. All of the producers, with the exception of Solvay Minerals, Inc., have on-site power generation facilities, which consume additional amounts of water. Water is also used for dust abatement and domestic supplies. All of the water at the facilities is discharged through cooling towers or evaporated from holding ponds.

Church and Dwight purchases soda ash from the General Chemical plant to produce baking soda and powdered laundry detergent. As presented in Table 5-13, this operation has recently used on the order of 160 acre-feet of water per year. This contrasts with 215 acre-feet of water per year reported in the previous basin plan (Green River Basin Plan, 2001).

Simplot Phosphates produces chemical fertilizer and obtains its water from the Green River/Rock Springs/Sweetwater County Joint Powers Board. Simplot Phosphates, LLC produces Phosphoric Acid (54%), Super Phosphoric Acid (68%) MAP Monoammonium Phosphate; a dry granulated fertilizer and FSA (Fluorosilic Acid). In 2000 the facility used approximately 560 acre-feet of water and used an annual average of 605 acre-feet per year from 2004 to 2008.

The remaining one percent of industrial water usage in the Green River Basin is consumed by small industries such as coal and uranium mining and oil and gas production. These collectively use approximately 1,874 acre-feet of water per year. Exxon's Shute Creek natural gas plant obtains its water through a direct flow right on the Green River and groundwater wells. The operation uses approximately 16 acre-feet of water per year. Table 5-13 provides recent estimates of the monthly and annual surface water use for the 10 largest industrial water users in the Green River Basin.

Green River flows are stored in Fontenelle and Flaming Gorge Reservoirs. Both of these dams have hydroelectric generating facilities. The production of hydropower is considered a non-consumptive use of water other than the associated reservoir evaporation losses which are considered in other sections of this report.

Table 5-13 - 2005-2006 Average Monthly Industrial Surface Water Use In Green River Basin

Month	January	February	March	April	May	June	July
	Acre-Feet						
Jim Bridger Power Plant[1]	2,642	1,939	2,626	1,815	1,879	2,122	3,134
Naughton Power Plant[1]	900	936	1,033	849	825	938	973
FMC Wyoming[1]	601	532	687	693	690	691	702
General Chemical[1]	294	291	307	289	298	287	312
OCI Wyoming[1]	263	201	200	220	273	286	223
Solvay[1]	204	169	194	197	190	195	218
Church & Dwight[1]	12	11	10	12	11	9	8
Exxon Shute Creek[2]	1	1	1	1	2	2	2
Simplot Phosphates[3]	48	46	57	54	44	51	54
Total Average Monthly Use	**4,965**	**4,126**	**5,115**	**4,129**	**4,212**	**4,581**	**5,627**

Month	August	September	October	November	December	Total
	Acre-Feet					
Jim Bridger Power Plant[1]	2,781	2,620	2,537	2,343	2,122	28,560
Naughton Power Plant[1]	1,062	980	941	822	855	11,114
FMC Wyoming[1]	666	612	493	450	545	7,362
General Chemical[1]	315	352	374	330	339	3,788
OCI Wyoming[1]	310	260	249	247	262	2,994
Solvay[1]	212	186	204	165	100	2,234
Church & Dwight[1]	30	25	11	11	11	160
Exxon Shute Creek[2]	2	1	1	1	1	16
Simplot Phosphates[3]	56	48	53	45	49	605
Total Average Monthly Use	**5,434**	**5,083**	**4,863**	**4,413**	**4,284**	**56,833**

Source: WWC Engineering, 2009 (I)

[1] From SEO Hydrographer Annual Report Div. 4.

[2] From 2001 Green River Basin Plan.

[3] Green River/Rock Springs/Sweetwater County Joint Powers Board 4 year average June 2004 to March 2008.

Groundwater Use

Overall groundwater use by industry in the Basin is estimated at 1,954 acre-feet annually. It is unlikely that industrial groundwater use in the Green River Basin has significant impacts on surface water flows due to its limited and sporadic use and the relative distance of most of the operations from major rivers and streams.

Black Butte Coal Company and Bridger Coal Company provide coal to the Jim Bridger Power Plant while Kemmerer Coal Company provides coal to the Naughton Power Plant. These companies have several permits for groundwater use, and the water generally comes from wells or as a by-product of the mining operations. Coal mines primarily use water for dust abatement. The Bridger Coal Company obtains water from the Jim Bridger Power Plant for domestic and fire protection use. Kemmerer Coal Company obtains domestic and fire protection water from Kemmerer/Diamondville Joint Powers Board.

The uranium industry is presently idle in the Green River Basin. Kennecott Uranium Company holds water rights for several groundwater wells at its inactive mine and processing facility in the Great Divide Basin. The water was used in the milling process to extract uranium from the ore.

Oil and gas companies often secure water rights to use the water for on-site purposes, such as producing drilling mud and dust abatement. Water use at the wells during the drilling process is typically short term.

5.5 RECREATIONAL WATER USE

Recreational uses of water are important and generally nonconsumptive. Uses include boating, fishing, swimming, skiing, golfing, and waterfowl hunting, as well as activities such as camping, hiking, and wildlife watching that are enhanced by water in streams, lakes, and rivers. While consumption of water is usually not involved, the existence of a sufficient water supply is important for a quality experience. This section describes current water-based recreational uses, in terms of specific activities and in terms of geographic locations.

Fishing

Fishing is a major water-based recreational activity in the Green River Basin with many places to take advantage of this activity including backcountry lakes, reservoirs, numerous small streams, the New Fork River, and the mainstem of the Green River. Sport fish species in these waters include native Colorado River cutthroat trout, brown trout, golden trout, brook trout, lake trout, rainbow trout, and mountain whitefish. Fishing is a non-consumptive use of water, but water quantity and quality are important to maintain habitat conducive to sport fish.

The Green and New Fork rivers are outstanding wade and floating fishing areas and are notorious for supporting a blue ribbon fishery. Outfitters offer guided fishing and float-fishing trips in the Green River Basin. Warren Bridge to Highway 351 is the most popular destination for float fishing and wade fishing in the Upper Green River. The Green River below Fontenelle Reservoir is also a popular destination. The quality fishery and the relatively easy river access make these sections of the Green River well-liked. There are more than 600 Bridger Wilderness lakes that support fish.

Seedskadee National Wildlife Refuge contains a high-quality cold water fishery that is sustained by flows from Fontenelle Dam, upstream of the refuge. Primary game species on the refuge include rainbow trout, brown trout, and cutthroat trout. Flaming Gorge Reservoir, at the southern edge of Wyoming's Green River Basin, supports a fishery that includes lake trout, Kokanee salmon, rainbow trout, brown trout, smallmouth bass, and channel catfish.

The Green River Basin has many fishing opportunities and is considered by many to provide excellent fishing opportunities in its lakes, streams, rivers and backcountry areas. The Wyoming Game and Fish Department maintains the most complete database on the Green River Basin fisheries and the utilization of the resource.

Boating

The streams, rivers, and lakes of the Green River Basin provide numerous opportunities for boating, water-skiing, and floating. These opportunities include canoeing on lakes, flatwater streams, and rivers; whitewater kayaking on small streams; float fishing; and long-distance river trips. The most popular boating destination is Flaming Gorge Reservoir. Other popular destinations include Fremont Lake and Fontenelle Reservoir.

The most popular boating destinations for fishing are along the Green and New Fork Rivers. Overnight river trips are increasing in popularity along the Green River, particularly in the northern reaches where public river access is available. While opportunities exist for whitewater kayaking on small tributary streams, the Green River Basin is not a major destination for kayakers.

Boating opportunities are generally dependent on streamflow, which is influenced by winter snowpack and reservoir releases which are usually dictated by other water uses. A quality boating experience requires a water level (in lakes) or flow rate (in rivers) sufficient to support the reason for boating, whether it is fishing, water-skiing or some other sport. In this context, future water development projects must be evaluated for their effect on such levels. Boating is considered a non-consumptive use of water.

Little quantitative data exist on the numbers of watercraft using these facilities and whether numbers approach or exceed the carrying capacity of the water body used. The Bureau of Reclamation has indicated that, while not the rule on Wyoming waters, a ceiling capacity of one boat per ten surface acres of water is used elsewhere to measure use versus capacity.

Waterfowl Hunting

Stable waterfowl populations are dependent on reliable open water and wetland habitat, and, therefore, are affected by hydrological changes that could influence the quality and availability of those areas. As a recreation activity, waterfowl hunting is therefore dependent on suitable water supplies, habitat, and waterfowl populations. While waterfowl hunting occurs throughout the Green River Basin where suitable habitat exists, some of the primary destinations for this activity include the Farson area and Seedskadee National Wildlife Refuge.

Harvest objectives have not been used since 1993 because the harvest is parameterized by the boundaries of season length and bag limits by the U.S. Fish and Wildlife Service (USFWS). In effect, the desired harvest is a prospective number using past hunter success, population effects, and regulations in concert with current-year populations. With current duck populations and hunting pressure, it appears there is a sufficient resource to provide a quality duck hunting experience now and in the near future with the existing water resources of the Basin.

In like fashion, goose hunting seasons and bag limits are set under guidelines from the USFWS, although states have flexibility in setting bag and possession limits. Also like duck populations, goose populations are strong and increasing and it appears there is a sufficient resource to provide a quality goose hunting experience now and in the near future with the existing water resources of the Basin. However, because the Rocky Mountain population nests and breeds locally, it is possible for local water development projects to adversely affect local goose populations (and hunter success) if breeding and nesting sites suffer net loss, even as continental populations continue to rise.

Skiing and Winter Sports

Downhill and nordic skiing, snowshoeing, and snowmobiling are all winter sports enjoyed in the Green River Basin; downhill skiing is the only recreational water consumer out of that list. Consumption is through evaporation during the snowmaking process, which has been estimated at about 20 percent consumptive. However, while downhill skiing is a consumptive user, the water use is a minor one. White Pine Ski Resort, located about 10 miles northeast of Pinedale, is the only lift-serviced downhill ski area in the Green River Basin. White Pine offers two triple chair lifts, about 25 trails, and a vertical drop of 1,100 feet. The resort has a limited snowmaking system, which draws water from a small reservoir in the Surveyor Park drainage. A plan is in place to expand snowmaking throughout most of the ski area. Actual water use of White Pine is not known. Based on USFS estimates, White Pine Ski Resort has about 30,000 skier days per year.

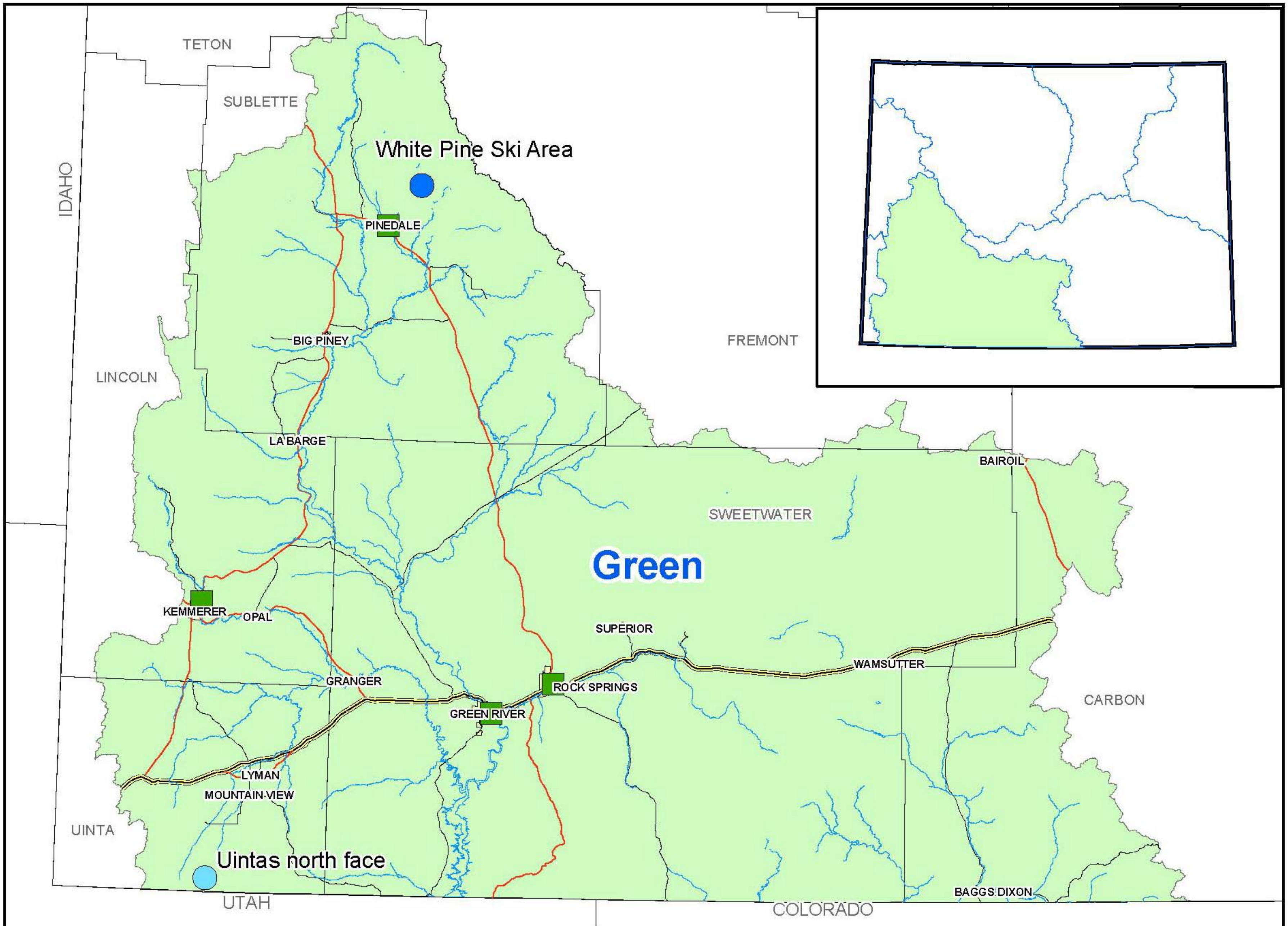
Several locations offer designated and groomed cross-country ski trails, including White Pine Resort, Skyline Drive, Kelly Park, and CCC Ponds areas near Pinedale. In addition, many ungroomed cross-country and backcountry ski routes are available on National Forest lands. A recent study found that nordic use in the Pinedale area is similar to alpine use at the ski area, making it a significant winter recreation attraction in the area. Other winter sports available in the Green River Basin include snowshoeing and snowmobiling.

Golfing

Golfing is a popular recreational activity in the Green River Basin. There are four golf courses in the Basin that provide a recreational amenity to residents and visitors. Major water use at golf courses is for irrigation of the greens and fairways. The use is often considered a municipal use, similar to park and cemetery use. While golfing is a consumptive use of water, the water use is minor compared to other uses. Figure 5-8 shows the locations of golf courses and ski areas in the Green River Basin.

Wyoming State Parks and Historical Sites

There are five State Historic Sites (SHS) and no State Parks in the Green River Basin. Water use at the State Historic Sites is primarily for drinking water and sanitation. Figure 5-9 shows the locations of state historic sites in the Green River Basin. About 86 percent of all visitations (to all parks and historic sites) occur in the months of June, July and August, with attendance in each of those months almost equal. Slightly over half the visitors are first-time visitors. Approximately one in four visitors are traveling with a boat or canoe, indicating some water-based recreation is intended, either at that location or elsewhere on that particular trip. Approximately 58 percent of the visitors are from out of state. In 2007 there were 29,559 visitors to Fort Bridger and 22,695 visitors to the Fort Bridger Museum, more visitors to Fort Bridger and less to the museum than in 2000.



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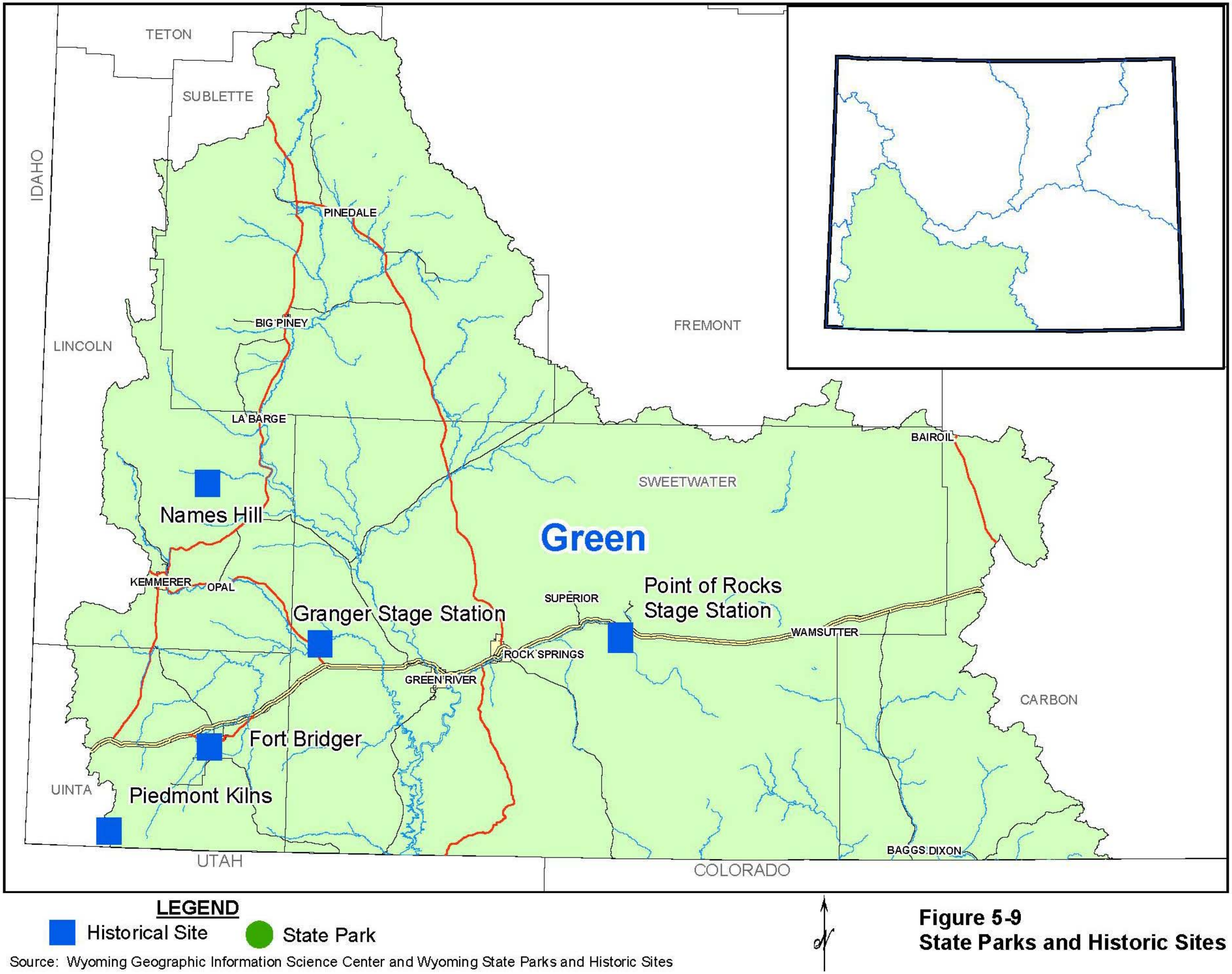
Downhill Ski Area Cross Country Ski Area Golf Course

Source: Wyoming Geographic Information Science Center

Figure 5-8
Ski Areas and Golf Courses



Source: Wyoming Geographic Information Science Center and Wyoming State Parks and Historic Sites

Figure 5-9
State Parks and Historic Sites

National Forests

National forests within the Green River Basin include Wasatch National Forest, Ashley National Forest, and parts of the Bridger/Teton National Forest and Medicine Bow National Forest.

Most of the headwaters of the Green River Basin are located within the Bridger-Teton National Forest, administered by the United States Forest Service (USFS). These areas support a variety of developed and undeveloped facilities that are either dependent on (e.g., boating and fishing access) or compatible with (e.g., camping areas) water-based recreation. USFS lands and recreation sites are managed by the Pinedale District (north and northeast areas), the Big Piney District (northwest areas), and the Kemmerer District (west areas). Recreation sites and facilities include the following:

- 17 developed campgrounds;
- Numerous unimproved camping sites; and
- Key destinations include the Green River lakes, the Green River, Fremont Lake, Boulder Lake, Willow Lake, New Fork Lake, Halfmoon Lake, Middle Piney Lake, North Piney Lake, the more than 1,000 Bridger Wilderness Lakes, and the Hams Fork River.

A small portion of the far southeast reaches of Wyoming's Green River Basin (Little Snake River drainage) is located within the Medicine Bow National Forest. This area generally supports dispersed fishing and camping opportunities, along with two developed campgrounds. The High Savery Reservoir is just west of the Medicine Bow National Forest. The Flaming Gorge National Recreation Area is administered by Ashley National Forest.

Bureau of Land Management

Most of the Green River Basin consists of public lands administered by the BLM, under the Pinedale, Rock Springs, Kemmerer, and Rawlins Field Offices. Most water-based recreation on BLM lands occurs along larger rivers such as the Green River, New Fork River, and Big Sandy River. Key water-related recreation sites administered by the BLM include the following:

- Upper Green River/Warren Bridge – Northwest of Pinedale. Includes 12 designated river access and camping sites as well as a developed campground at Warren Bridge.
- Boulder Lake – East of Pinedale. Includes two campgrounds (North Boulder Lake and Stokes Crossing) that support boating, fishing, and other recreation activities.
- CCC Ponds – East of Pinedale. Includes a series of ponds and trails that provide fishing opportunities as well as hiking, biking, and cross-country skiing trails.
- New Fork Campground – Near Boulder. Includes a rustic campground and river access for boating and fishing.

Summary of Recreational Use

The Wyoming Business Council tracks recreation and tourism trends throughout the state. Based upon the most recent visitor surveys taken in 2008, 11 of the top 15 outdoor recreation activities in Wyoming are either water-based (boating, fishing, skiing) or water-related (hunting, camping, birdwatching). The top outdoor recreational activities in Wyoming are listed below with water-dependent or water-related activities in **bold**:

	Outdoor Activity	Percent of Visitor Participation
1.	**Wildlife Watching**	**39.5%**
2.	Hiking or backpacking	21.4%
3.	**Camping**	**15.1%**
4.	**Bird Watching**	**11.9%**
5.	**Fishing**	**10.8%**
6.	Bicycling	8.0%
7.	**River Rafting**	**7.7%**
8.	**Snow skiing/snowboarding**	**5.8%**
9.	**Boating**	**5.1%**
10.	**Canoeing or kayaking**	**4.5%**
11.	**Hunting**	**3.8%**
12.	Mountain Climbing	3.7%
13.	**Snowmobiling**	**3.4%**
14.	**Golfing**	**2.7%**
15.	Rock Climbing	2.2%

In general, the recreational uses of water in the Green River Basin are nonconsumptive, but these uses do require an adequate supply of water. This water use is important for contributions to the local economy and the less-tangible benefits of lifestyle quality that recreation opportunities provide to both residents and visitors. These benefits vary by activity and individual, but generally include exercise and relaxation, as well as opportunities to spend time with friends and family. Economic benefits include both recreation and recreationally-based travel which generated more than $550 million in spending within the Green River Basin in 2007 and created 5,750 jobs in the same time period. Over the 10-year period from 1997 to 2007, travel-related spending in the Green River Basin has grown at a rate of 8.4 percent, while employment has grown 2.9 percent. Growth in spending and employment in the Green River Basin has outpaced statewide trends.

5.6 ENVIRONMENTAL WATER USE

5.6.1 Introduction

Environmental water uses include the water needed to support fish and other water-dependent plant and animal species and the associated water-dependent ecosystem functions. In all, about 1.5 million acres of land in the Green River Basin rely on water from streams, reservoirs, and irrigation to support a variety of environmental water needs. Environmental water uses are primarily non-consumptive, with many of the benefits to the environment accruing from the natural flow in streams and rivers, as well as the storage, distribution, and use of water for other primary purposes.

Previous studies conducted by the WWDC, SEO, the USFWS and the WGFD have estimated the amount of water designated for or consumed by various environmental uses. These include but are not necessarily limited to instream flow water rights permitted by the Wyoming State Engineer, minimum reservoir pools, instream bypasses designated to enhance fisheries and wildlife habitat, wetlands, direct wildlife consumption, evaporation from conservation pools and maintenance of riparian areas. Environmental uses downstream on the Green and Colorado Rivers must also be considered such as those needed to restore habitat of Colorado River cutthroat trout.

5.6.2 Current Water Use

Environmental water uses are generally nonconsumptive and therefore do not have a specific use assigned to them. The following environmental factors need to be considered when discussing water use.

Instream Flows

Wyoming's instream flow statutes recognize the economic fact that water resources have value in nonconsumptive uses such as instream flows. Such flows not only contribute to aesthetic character and biological diversity of the river basin planning areas, they also support recreational fisheries that are important to river basin residents and to the river basin and state economies. Reductions in streamflow can affect the quality of water by increasing temperature and concentrations of constituents to levels deleterious to aquatic life. Lower streamflows also can impact the composition and distribution of wetland and riparian habitats that are critical to amphibians, birds, waterfowl, and mammals in an arid environment.

The Instream Flow Law, passed in 1986 by the Wyoming Legislature, allows for the maintenance of streamflows to be considered a beneficial use of water. Designation of instream flow water rights are regulated under Wyoming Statutes, Article 10-Instream Flows, 41-3-1001, et seq. Under these statutes, "unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flows to maintain or improve existing fisheries and declared a beneficial use of water by the WSEO, if such use does not impair or diminish the rights to any other appropriator." Only the WGFD through the State Game and Fish Commission can apply for an instream flow permit. The WGFD completes biological studies to determine what instream flows are necessary to support and maintain the form, function, and ecological processes of a river. After the WGFD identifies stream segments where instream flow protection is needed to maintain the fishery and makes a determination of the water necessary to maintain or improve the fishery, the Wyoming Water Development Commission (WWDC) assesses the hydrologic feasibility of the permit. The feasibility study includes a determination of hydrologic conditions and the availability of unappropriated water. The WSEO then holds a public hearing prior to making the decision regarding the amount of instream flow. Based on this information and public input, the WSEO then issues a decision on the permit. The WWDC holds the water right for all instream flow permits.

Several rivers and streams in the Green River Basin are permitted for instream flow water rights and several are in the process of being studied by the WGFD to determine appropriate flows. Figure 5-10 shows the locations of all current instream flow permits. Many filings for instream flow permits are on streams containing Colorado River cutthroat trout, and are intended to help protect that species, which is being considered for listing as an endangered species under the federal Endangered Species Act.

For most streams and rivers that are permitted for instream flow water rights, the WGFD has determined that a seasonal range of values is required to sustain a healthy environment for fish and other wildlife rather than a constant flow. The WGFD has also estimated stream maintenance flows for several other streams in the Green River Basin that do not have instream flow rights. These values are preliminary estimates of the flows necessary to support game fish populations in the late season during low flow months. A WGFD application for an instream permit for these or other drainages in the Green River Basin could occur in the future upon further study and in accordance with the instream flow permitting process. There is no enforcement or legal water rights associated with WGFD stream maintenance values.

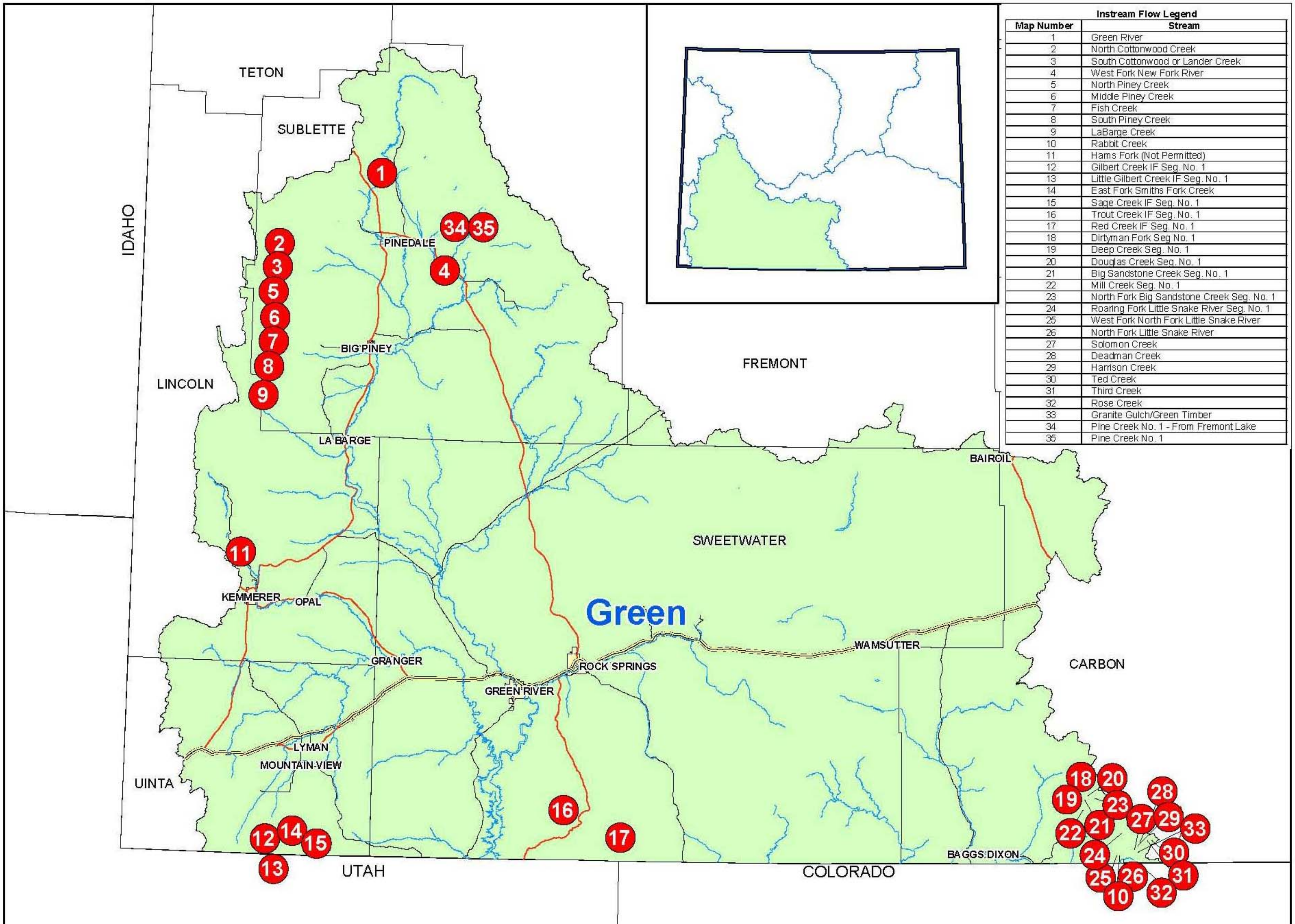
Reservoir Minimum Pools

Several reservoirs in the Green River Basin have storage permitted for a variety of environmental uses. These uses, as they appear on the water rights, include fish or fish and wildlife. Recreational uses defined on permits can be considered environmental to the extent that water in storage for recreational purposes, and not released for other consumptive or nonconsumptive uses, can be environmentally beneficial for fish habitat and wildlife consumption. Reservoirs with permitted capacity for stock water similarly serve a dual environmental function. Reservoirs with fish or fish and wildlife uses or pools listed in their permitting documents include:

- Boulder (1,621 acre-feet)
- High Savery (5,724 acre-feet)

Reservoirs that have an un-segregated portion of their total storage devoted to fish and wildlife (or similar use):

- Big Sandy
- Flaming Gorge
- Fontenelle



Instream Flow Legend

Map Number	Stream
1	Green River
2	North Cottonwood Creek
3	South Cottonwood or Lander Creek
4	West Fork New Fork River
5	North Piney Creek
6	Middle Piney Creek
7	Fish Creek
8	South Piney Creek
9	LaBarge Creek
10	Rabbit Creek
11	Hams Fork (Not Permitted)
12	Gilbert Creek IF Seg. No. 1
13	Little Gilbert Creek IF Seg. No. 1
14	East Fork Smiths Fork Creek
15	Sage Creek IF Seg. No. 1
16	Trout Creek IF Seg. No. 1
17	Red Creek IF Seg. No. 1
18	Dirtyman Fork Seg No. 1
19	Deep Creek Seg. No. 1
20	Douglas Creek Seg. No. 1
21	Big Sandstone Creek Seg. No. 1
22	Mill Creek Seg. No. 1
23	North Fork Big Sandstone Creek Seg. No. 1
24	Roaring Fork Little Snake River Seg. No. 1
25	West Fork North Fork Little Snake River
26	North Fork Little Snake River
27	Solomon Creek
28	Deadman Creek
29	Harrison Creek
30	Ted Creek
31	Third Creek
32	Rose Creek
33	Granite Gulch/Green Timber
34	Pine Creek No. 1 - From Fremont Lake
35	Pine Creek No. 1

LEGEND

1 Instream Flow Segment

Figure 5-10
Instream Flow Segments

Direct Wildlife Consumption

Habitat for wildlife species in the Green River Basin is an important component of water needs and includes areas such as open water, riparian, shores, and wetlands. The largest water users include elk, mule deer, antelope, and other big game species, although consumptive water use also occurs for smaller mammals, birds, and other species. Quantifying consumptive water use is challenging because of the uncertainties about wildlife population and specific animal water needs. Previous investigations have estimated direct wildlife water consumption in the Green River Basin is likely around 400 acre-feet per year. In relation to other water uses in the Green River Basin, direct wildlife consumption is a minor component of overall water use.

Threatened and Endangered Species

Water-dependent threatened and endangered species are defined as species that spend more than one-half of their lives in water, shores, wetlands, or riparian areas. The presence of threatened or endangered species of plants and animals or of species that might be considered for such listing can make water management and development more complex. Federally listed threatened and endangered species that are dependent on water, wetlands and riparian areas in the Green River Basin include five species of fish and one species of wetland plant. State listed species of concern on water, wetland, and riparian area in the Green River Basin include 15 birds, 4 amphibians, 3 mammals, 10 fish, and 32 plants.

There is no designated critical habitat for threatened or endangered species in Wyoming. However, critical habitat for the Colorado pikeminnow, razorback sucker, bonytail, and humpback chub has been designated at downstream locations outside of Wyoming in the Yampa River from Craig, Colorado to the Green River, the White River from Rio Blanco Dam to the Green River, and the Green River from Dinosaur National Monument to Lake Powell. Changes in Green River flows or water quality in Wyoming have the potential to impact downstream habitat for these endangered fish species.

Kendall Warm Springs is the only known habitat of the Kendall Warm Springs Dace, a unique fish subspecies and endangered under the Endangered Species Act. The fish resides only in a warm spring tributary to the Green River, within the Bridger-Teton National Forest. Historic threats to this fish included habitat degradation, over-collection and pollution from detergents and soaps.

The Colorado cutthroat trout is of particular concern because it is the only native trout present in the Green and Little Snake River drainages. The WGFD has instituted a management program designed to protect and enhance the natural populations of Wyoming's native cutthroat trout. The WGFD has been actively working to restore habitat for the species in the LaBarge Creek drainage and in the headwaters of the Little Snake River on the west slope of the Sierra Madres. Management of the trout is intended to prevent the species from becoming listed as threatened or endangered and in 2007 it was determined that listing these species as threatened or endangered was not warranted. Work involved in protecting this native fish is considered non-consumptive of water, although the use of instream flow water rights and habitat improvement will affect future water development activities in the immediate vicinity of such work. The Upper Colorado River Endangered Fish Recovery Program in 2008 received the Cooperative Conservation Award (CCA) from the U.S. Department of the Interior for significant contribution and outstanding collaboration efforts among federal and non-federal entities who are accomplishing on-the-ground conservation achievements.

The Wyoming Natural Diversity Database (WNDD) lists 460 plant species of concern in the State of Wyoming. Of those sensitive plants listed, 32 species are listed as facultative wetland or obligate wetland and potentially occur in Carbon, Lincoln, Sublette, Sweetwater, and Uinta Counties. Facultative wetland species are plants that typically occur in wetlands, but occasionally are found in non-wetlands; obligate wetland plants almost always occur in wetlands. These wetland plant species are dependent on the various water sources in the Green River Basin that contribute to providing suitable habitat.

Wetlands

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of classification, wetlands must have one or more of the following three attributes:

1) At least periodically, the land supports predominantly hydrophytes;
2) The substrate is predominantly undrained hydric soil; and
3) The substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year.

Wetlands provide food, shelter, and breeding habitat for waterfowl and other wildlife. They may improve the water quality by contributing to the removal of nutrients, sediment, and other impurities in water, in turn protecting rivers and lakes and help control erosion and flooding during high water events. Wetlands are protected under the Clean Water Act and any activities that require the dredging or filling of wetlands are subject to permitting and mitigation requirements.

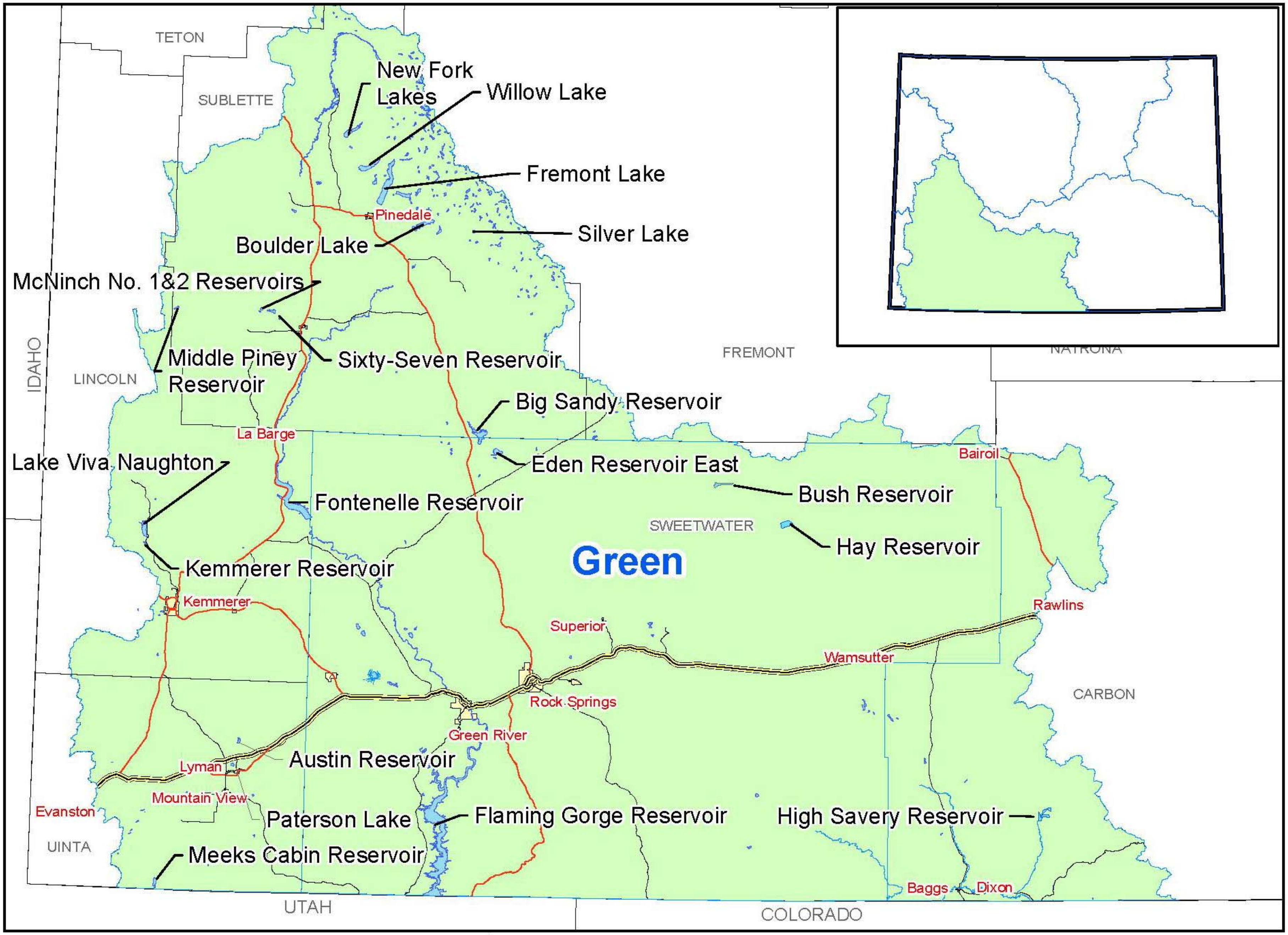
About 383,000 acres are mapped as wetlands in the Green River Basin based on National Wetlands Inventory (NWI) mapping. No NWI digital wetland mapping was available in the northern portion of the Green River Basin; therefore, estimates of total wetland acreage are understated. Wyoming Gap Analysis (WGA) mapping indicates that about 452,000 acres of irrigated croplands are present in the Green River Basin and are comprised of row crops, alfalfa fields, irrigated native meadows, and orchards. Comparison of the NWI mapping with WGA mapping indicates that NWI wetlands include some 177,000 acres of irrigated land in the wetlands mapping acreages. These are most likely to include irrigated meadows that support wetland vegetation or other mesic grass and forb species on seasonally wet soils.

Wetlands in the Green River Basin provide significant nesting and breeding habitat for local populations of ducks and geese. In fact, the Green River Basin is an important contributor to Wyoming's status as one of the largest waterfowl resident states in the western U.S., with the total number of duck breeding pairs more than double the total in Nebraska and Colorado combined for 1999. These local birds are the primary target of waterfowl hunters, and as such their reproductive success is important to future environmental and recreational pursuits. In the Green River Basin, areas near Farson, Eden and the Seedskadee National Wildlife Refuge are the most heavily hunted for waterfowl.

The Seedkadee National Wildlife Refuge (NWR) provides important wetland and riparian habitat. Created initially as environmental mitigation following construction of Flaming Gorge and Fontenelle Reservoirs by the Bureau of Reclamation, the refuge contains 26,037 acres of land and covers over 36 miles of the main stem of the Green River. Seedskadee NWR provides significant water-related environmental benefits in an otherwise arid region. The refuge provides riparian, wetland, riverine, and upland habitats supporting migrating songbirds, bald eagles, several hawk species, moose, and mule deer. Wetlands are managed to provide habitat for birds such as trumpeter swans, ruddy ducks, white-faced ibis, redheads, cinnamon teal, pie-billed grebes, sora rails, and marsh wrens. The source of water for these uses is the Green River with contributions from the Big Sandy River. In a 1974 contract between the State of Wyoming and the Bureau of Reclamation, 5,000 acre-feet of reservoir water was designated for the refuge. In addition, Seedskadee uses older pre-refuge irrigation works to distribute water for wetland development and maintenance, and benefits from 115 cfs of direct flow rights held by the U.S. Bureau of Reclamation. Consumption of water on the refuge is limited to evapotranspiration from the wetland and riparian areas. Currently, the refuge has no plans to create significant new wetlands, although maintenance of existing wetlands and reestablishment of pre-existing wetlands will continue. Currently there are approximately 335 acres of wetland habitat and 1,394 acres of riverine habitat on the refuge.

5.7 EVAPORATION

The Green River Basin contains several large reservoirs used for various purposes including storage for irrigation, municipal, industrial, recreational, fish propagation and flood control, among others. Figure 5-11 shows the locations of major reservoirs over 1,000 acre-feet in capacity. These reservoirs help sustain water uses in this arid to semi-arid land by capturing surplus flows during wet seasons and high-runoff years and releasing the stored water during drier seasons. Naturally, the surface area of a reservoir provides more evaporation than occurred prior to reservoir construction. For the average or normal condition, it was estimated in the 2001 Green River Basin Plan that reservoir evaporative loss amounts to about 121,300 acre-feet per year.



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Reservoir

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Figure 5-11
Major Reservoirs

5.8 SUMMARY OF CHANGE IN WATER USE

Table 5-14 summarizes amount of water use by the water-use sectors for the 2001 Green River Basin Plan and the current Green River Basin Plan.

Agricultural water use appears to have decreased since 2001, although reasons for this are not clear. Part of the reason may be due to differences in the irrigated acreage and consumptive irrigation requirement (CIR) calculation methodologies between the two plans. Diversion records were used by the previous Green River Basin Plan to estimate irrigation days, and it appears that every day the ditch was diverting, the full CIR under the ditch was assumed to be met. The current analysis shows that this assumption may slightly over-estimate consumptive use. Key ditches carry senior and junior rights and, especially as supply becomes more limited in the late summer, diversions seldom meet full CIR. Therefore, the analysis performed for this project shows less irrigation consumptive use than was reported in the 2001 Green River Basin Plan.

Municipal water use has increased since 2001, a clear reflection of greater demands on the municipal water system by a growing population. Rural population increased along with urban population, with a corresponding rise in domestic water use. The number of domestic groundwater well permits also increased since 2001, reflecting a larger rural population, more domestic wells, and more domestic water use.

Industrial use of surface water, most of which is cooling water for power plants, has decreased by about 15% since 2001, a result that is hard to explain in the light of increased production rates of most of the industrial water users. One possible explanation could be the more accurate method of collecting surface water depletion estimates in the 2010 Green River Basin Plan than the 2001 Plan.

In 2001, the soda ash industries did not have any records of their water use, so an “industry rule of thumb” was used to calculate consumption, namely that it takes 200 gallons of water to produce one ton of soda ash. At 2005-2006 levels of production and conditions the four producers reported depletions of approximately 16,400 acre-feet of water from the Green River as reported in the SEO Hydrographer’s 2006 annual report.

Industrial groundwater use has increased nominally, most likely a result of work beginning on the Atlantic Rim Coalbed Methane Project, which was in its development phase in 2001. The full field development of Green River Basin Coal Bed Natural Gas (CBNG) in 2001 predicted drilling a maximum of 3,880 wells on 310,335 acres over six to ten years with a project life of 20 to 30 years. Because of high gas prices the number of CBNG permit applications filed in 2000 and 2001 peaked at 6,093 applications from 55 companies. The number of permit applications declined to 2,157 by 30 companies in 2008 due to lawsuits, more stringent water discharge requirements, lack of pipeline infrastructure, and the decline of natural gas demand and prices with the weaker national economy. Although CBNG well permit applications have dropped since peaking in 2000 and 2001, the number of wells pumping groundwater has increased from zero in 2000 to about 477 in 2008. Thus the number of CBNG wells has increased substantially since the first Green River Basin Plan and accounts for a large part of increased industrial groundwater use.

Recreational and environmental water uses have remained stable. The only noteworthy increase that could occur in these sectors would be the result of the allocation of water to consumptive water uses, such as allocating more water to the Seedskadee National Wildlife Refuge, a new wetland refuge, or building more golf courses, which are the only sources of recreational water consumption. None of these changes occurred from 2001 to 2007.

Table 5-14 - Summary of Change in Water Use

Sector of Use	Type of Use	GRBP I 2001	GRBP II 2010	% Difference
		Acre-Feet/Year		
Agricultural	Irrigation[1]	401,034	396,246	-1
	Stock	N/A	1,755	N/A
Municipal	Surface Water[2]	6,539	6,578	0.60
	Groundwater	812	884	9
	City of Cheyenne Diversions	14,388	15,281	6
Domestic	Surface Water	≈0	≈0	0
	Groundwater[3]	2,904	3,047	5
Industrial	Surface Water	66,491	56,833	-15
	Groundwater	1,575	1,954	24
Recreational		Non-consumptive		0
Environmental		2,000	Non-consumptive[4]	N/A
Evaporation	Main Stem	88,500	88,500	0
	In State	32,800	32,800	0
TOTAL		**617,043**	**603,878**	-2

[1] Water use values based upon normal year estimates of surface water and groundwater use.
[2] Does not include diversions for the City of Cheyenne.
[3] Values reflect the average of the calculated range of domestic groundwater use.
[4] Environmental was determined Non-consumptive.
Source: State Engineers Office Hydrographers Reports, 2008.

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6.0 PROJECTIONS

This chapter presents estimates of water demand in the Green River Basin through year 2055 for each major water use sector. Historic demographic and economic information was collected and related to water use in the previous sections of this report. In this section these water-use relationships are applied to three possible growth scenarios, high, medium and low, to provide a possible range of future water requirements by economic sector in the Basin.

6.1 FUTURE ECONOMIC AND DEMOGRAPHIC SCENARIOS

6.1.1 Overview of Planning Scenarios

The development of the high, medium and low growth projections employed various forecasting approaches that incorporated insights on overall regional growth patterns from local planning officials and industry representatives. Overviews of these scenarios are provided below:

High Growth Scenario

The high scenario incorporates an estimation of the most growth in the Green River Basin that could be expected under favorable economic conditions. High growth in the Basin will likely depend on a robust national economy and rising commodity prices (particularly cattle and sheep, coal, oil and gas, trona and possibly uranium), all of which figure prominently in the Basin's economy.

Medium Growth Scenario

The medium growth scenario represents the most realistic level of growth likely to occur in each of the key sectors and in the region over the planning period. Although the actual economic growth experienced may vary somewhat from this projection, the assumed activity levels represent the rate of growth most likely to be experienced in the Green River Basin. As such, this scenario may be the most useful for water planning purposes. This scenario is based largely on the assumption that trends of the past two or three decades will reasonably represent the future, and nothing will happen to drastically alter the prevailing economy and lifestyle in the Basin.

Low Growth Scenario

The low growth scenario embodies the estimated lowest growth (or largest contraction) reasonably likely to occur in the Green River Basin over the planning horizon. It assumes that the recession of the last two or three years, with its high rate of unemployment, fairly low commodity prices, and reduced industrial output will continue into the future.

6.2 AGRICULTURAL DEMAND PROJECTIONS

6.2.1 Introduction

As discussed in Chapter 3, agriculture in the Green River Basin is dominated by livestock production. The primary use of irrigation is to generate a winter feed base for the livestock enterprises in the Basin and the bulk of the irrigated land is devoted to the production of forage crops (alfalfa, grass hay, and irrigated pasture). Small amounts of grain are grown on irrigated acreage along the Blacks Fork and Smiths Fork Rivers, the lower Little Snake River Basin, and in the Eden Valley area. In other parts of the Basin, forage crops constitute effectively 100 percent of irrigated agricultural production.

The factors that will most likely have the largest potential impact on the economic prospects for agriculture are the demand for and price of beef. The state agriculture sector generated about $965,800,000 of total cash receipts in 2005; livestock and associated products made up 84 percent of these receipts and the Green River Basin agriculture sector is even more dependent on livestock and its associated products than the state as a whole. Other potential factors that may significantly impact agriculture include changes in public land grazing policies, second home and subdivision development, the aging of the ranching population, and management of cattle range and associated stockwater supplies. The following are summary descriptions about the prospects of agriculture in the Green River Basin over the planning period under each of the growth scenarios. Agricultural consumptive use projections for all three planning scenarios are presented in Table 6-1 and in Table 6-12 in the summary section.

High Growth Scenario

The high-growth scenario is based on increasing cattle prices and higher prices for export forage crops over the planning period. This scenario is based upon the reasonably foreseeable possibility that cattle prices will increase significantly in response to increased demand for high quality beef in Mexico and Canada due in part to North American Free Trade Agreement (NAFTA) and increasing demand in the Pacific Rim markets. Cattle prices are projected to stabilize at these higher prices over the planning horizon and thus provide a financial incentive for ranchers in water-short areas of the Basin to develop storage facilities for dry year and late season water supplies. Cattle and sheep numbers are projected to increase over the planning horizon. In the high-growth scenario, as cattle and sheep numbers increase over the planning period, high forage crop prices will encourage Basin irrigators to produce alfalfa and grass hay as cash crops, in addition to providing feed for their own livestock. Alfalfa is typically grown in lower elevation areas of the Basin and production could be expanded in those areas. The hay would be exported from the Basin to other states and some new lands may be irrigated to accommodate the growth in demand. In higher elevation areas of the Basin, irrigators could diversify into high-quality grass hay as a cash crop in addition to producing mixed grass hay for winter feed. Some of the hay would be exported out of the Basin to surrounding states, where high-quality grass hay is in high demand as horse feed. Any significant increase in the number of irrigated acres in the Basin will require the use of storage to supplement streamflow, which is typically over-appropriated after the spring runoff ends.

If agricultural prices increase or stabilize at higher levels, additional storage could be economically feasible. To date, the sub-basins that exhibit the greatest need for additional irrigation water have not been as aggressive in pursuing water development projects as other sub-basins. Forage crops that can be grown in the relatively high elevations of the Green River Basin have a small rate of return compared to the crops that can be grown under irrigation in the lower basin states of Arizona and California. The best scenario likely to lead to development of water projects to support irrigation of forage crops in the Green River Basin would be the expectation of high cattle prices over the planning period. Considering the history of the livestock industry, with fluctuating livestock prices, droughts, high fuel costs, changes in management of public lands, and other factors, it is difficult to get private investors to make long-term commitments to fund water development projects. As in the past, subsidies will be necessary to develop new water supplies for agriculture in the Basin. Even then, the irrigators will have to bear a portion of the costs by committing to a long-term loan repayment agreement. The level of irrigation water costs that the Basin irrigators are willing to accept will be a controlling factor in the level of future development under the high growth scenario.

The 2001 Green River Plan projected a depletion increase of 8,000 to 12,000 acre-feet annually would be associated with new storage projects along the northwest tributaries. Another 10,000 acre-feet of annual consumptive use was projected to be associated with future projects identified by the Little Snake River Water Conservation District. Based on the volume of studies requested in the northwest tributaries area and the Little Snake River sub-basin, it is logical to assume that those areas are the most likely to develop new storage. These assumptions of future development, totaling 18,000 to 22,000 acre-feet per year of new depletions, were carried forward into the high-growth scenario for this plan.

From the previous chapters it is estimated that irrigation in the Green River Basin consumes about 1.2 acre-feet per acre per year. This is based on 396,246 acre-feet of consumptive use from Table 5-6 and about 334,500 acres of irrigation from Table 5-1. Even in the high-growth scenario, a modest increase in irrigation is projected. The preliminary water use projections for the high-growth scenario estimate an additional 26,000 acre-feet of irrigation water will be consumptively used annually, increasing average annual consumptive use to about 423,000 acre-feet annually, or by a modest 6.5%. Considering the lack of change since the 1970 Basin plan was prepared, this seems reasonable and may be optimistic even for the high-growth scenario. If the projects in the northwest tributaries and the Little Snake River Basin deplete the additional 18,000 to 22,000 acre-feet per year as projected above, this would leave about 4,000 to 8,000 acre-feet of new consumptive uses to be developed in other parts of the Basin if cost-effective reservoir sites can be identified.

An additional consumptive water use by the agriculture sector is the direct consumption of water by livestock. Under the high-growth scenario, the number of animal units is projected to increase from 156,767 in 2005 to 203,035 in 2055. At 10 gallons per day of water consumption per animal unit, the consumptive use by livestock is projected to increase from 1,755 acre-feet in 2005 to 2,273 acre-feet in 2055 for the high-growth scenario.

Medium Growth Scenario

The medium-growth scenario is based upon the similar assumptions as above regarding future livestock prices. Cattle and sheep numbers are projected to increase over the planning period. Irrigation consumptive water use is projected to increase over the planning horizon from about 396,000 acre-feet in 2005 to about 406,000 acre-feet in 2055, or about 10,000 acre-feet per year. The number of animal units is projected to increase from 156,767 in 2005 to 183,581 in 2055, also about half the increase as projected in the high-growth scenario. Direct consumptive use is projected to increase from 1,755 acre-feet in 2005 to 2,055 acre-feet in 2055 for the medium-growth scenario.

The combination of projected higher cattle prices and potential WWDC assistance through their new Dam and Reservoir section may allow irrigators to develop some new storage projects in those parts of the Basin that are in the greatest need. Such developments might take place in the Blacks Fork sub-basin and along the northwest tributaries of the Upper Green River, where there is less storage per irrigated acre than other sub-basins. The producers in these two areas suffer water shortages during dry years and are chronically short of late season irrigation water and would have a large incentive to develop new storage if cattle prices increase as projected in this scenario.

Over the past 20 to 30 years there have been numerous studies investigating the feasibility of additional storage in the Green River Basin. A 2007 study (unpublished report by Dams and Reservoirs Division, Wyoming Water Development Office) identified four sites upstream of Fontenelle Reservoir that had potential to help satisfy identified water shortages in the Upper Green River sub-basin. Three of the sites are located in the northwest tributaries area and the remaining one is located in the New Fork drainage. The three northwest tributaries sites are Mickelson Creek, Horse Pasture Draw, and Cow Gulch, all off-channel sites. The site in the New Fork drainage is Lower Willow Creek, an on-channel site. These four sites could provide approximately 49,500 acre-feet of new storage. Additional sites identified by the WWDC in the northwest tributaries area are Sand Hill and McNinch Wash, both off-channel sites. It seems likely that some of the more cost-effective sites identified in the WWDC studies could be developed if financial returns to cow-calf operations and WWDC assistance increase as projected over the planning period. The medium-growth scenario is based upon the assumption that an additional 25,000 acre-feet of storage is developed along tributaries of the Upper Green at sites identified by WWDC or at alternative sites identified in the future as well as 5,000 acre-feet of additional storage along the Little Snake River.

Low Growth Scenario

The low-growth scenario is based upon the assumptions that irrigation in the Basin will continue to be dominated by forage production for winter livestock feed and that cattle and forage prices will not make sustained increases over the planning period.

Under the low-growth scenario, there may be a small reduction in total irrigated acreage in the Basin as some lands are taken out of production due to alkalinity and salinity problems, and other lands are converted to home sites in the more scenic parts of the Basin. Forage production will probably increase somewhat as irrigators adopt better water management techniques and production practices. This increase in forage production may allow cattle numbers to increase modestly over the planning period. Irrigation consumptive use is expected to decline from about 396,000 acre-feet in 2005 to about 386,500 in 2055 on average. The number of animal units is projected to increase to 169,800 in 2055. Direct consumptive use is projected to increase from 1,755 acre-feet in 2005 to 1,901 acre-feet in 2055 for the low-growth scenario. This scenario does not project the need for any new water storage projects for irrigation.

Summary

Table 6-1 summarizes agricultural consumptive use projections for the planning scenarios described above. The potential for increased forage production in the Green River Basin as a cash crop is likely further into the future than was anticipated in the 2001 Green River Basin Plan.

Table 6-1 - Green River Basin Projected Agricultural Consumptive Use

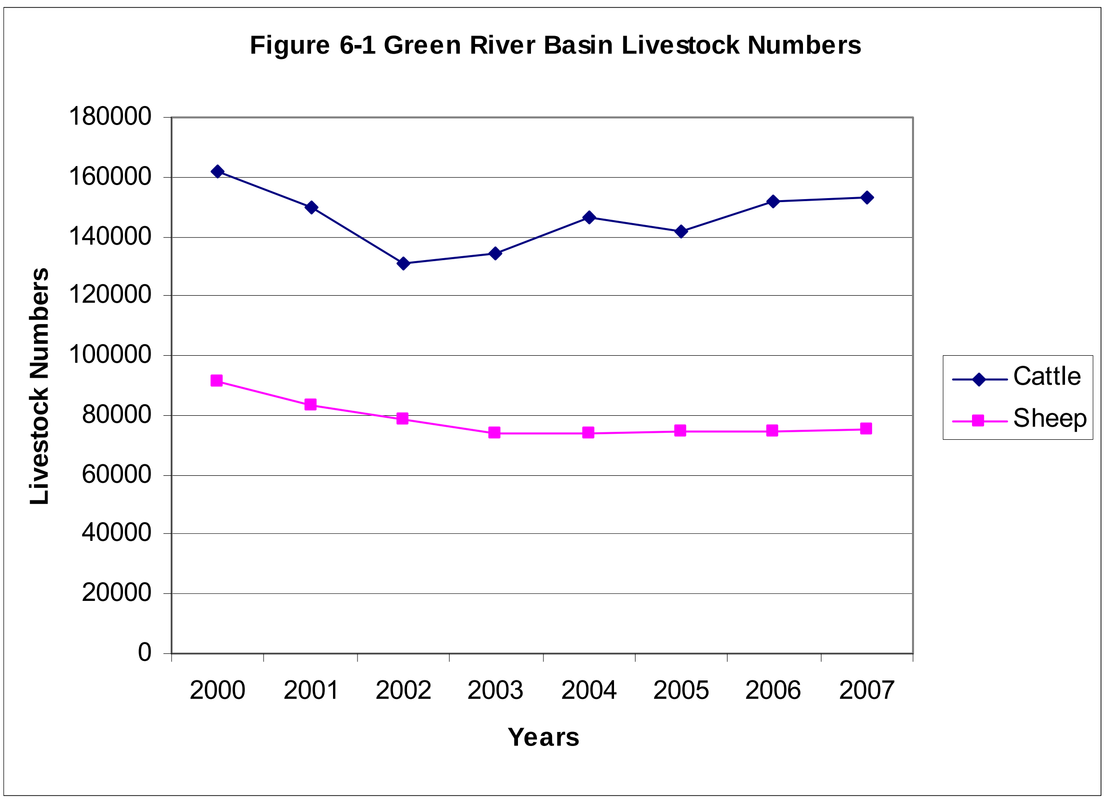
	Irrigation Consumptive Use in Acre-Feet					
Year	**2005**	**2015**	**2025**	**2035**	**2045**	**2055**
Low Growth	396,246	394,275	392,313	390,361	388,419	386,487
Medium Growth	396,246	398,227	400,218	402,219	404,231	406,252
High Growth	396,246	400,208	404,211	410,274	416,428	422,674
	Animal Unit Consumptive Use in Acre-Feet					
Year	**2005**	**2015**	**2035**	**2055**		
Low Growth	1,755	1,784	1,842	1,901		
Moderate Growth	1,755	1,812	1,930	2,055		
High Growth	1,755	1,848	2,049	2,273		

Source: “Irrigation Water Needs and Demand Projections,” tech. memo, WWC Engineering, 2009

*One animal unit is equal to one cow or five sheep.

**Animal Unit consumptive use is equal to 10 gallons per animal unit per day.

It was reported in the 2001 Green River Basin Plan that total animal units in the Basin were increasing. Recent inventory numbers indicate that the livestock numbers are fairly stable although there has been a shift from sheep production to cattle production. Figure 6-1 shows the cattle and sheep inventories for the Green River Basin. There appear to be several interrelated reasons why livestock production in the Basin has remained fairly stable rather than expanding as projected in the 2001 Green River Basin Plan. One is the drought that prevailed in recent years. Another limiting factor with respect to herd size is the availability of summer range on federal lands, which constitute a large proportion of the rangeland in the Basin. There has been little opportunity for producers with federal grazing allotments to increase production on federal land, and in some cases federal grazing rights have been restricted. The only alternative available for increased livestock production in the Basin has been more intensive use and management of private lands, which can involve either increasing forage production on existing irrigated acreage or bringing new acreage into production. Bringing new irrigated acreage into production is a capital-intensive option that has not been financially feasible for most producers. There has been some increase in forage production on existing irrigated lands through more use of fertilizer and better water management practices, such as the switch from flood to sprinkler irrigation.



Source: “Irrigation water needs and Demand Projections,” tech. memo, WWC Engineering, 2009

6.2.2 Future Water Needs and Demands

To project future irrigation water uses in the Green River Basin, it was necessary to consider both needs and demands for irrigation water. For the purposes of this report, the need for water is defined as consumptive irrigation requirement (CIR) and is a function of types and acres of crops being grown. Demands are distinguished from needs by the fact that they are a function of crop and livestock prices. For example, an irrigator may need a certain amount of water to produce a certain number of tons of forage on a given acreage. If the cost of providing this water exceeds what the irrigator is willing to pay, there may be no demand for the water even though there is a need for water. Many of the irrigated lands in the Basin, particularly where they depend solely on direct flow and have no water storage, receive less than an ideal water supply. Thus, there is a need for more irrigation water and there could be a demand for water if an affordable supply could be developed.

Livestock and forage crops are commodities, and individual operators have little if any control over prices they receive. Likewise, ranchers have little control over the cost of inputs to their production process (e.g., fuel and grazing fees). Commodity prices and fuel prices are subject to fluctuations, making irrigators reluctant to invest in expensive water development projects. The result is an industry in which producers are very sensitive to the price of water and their demands for water can change dramatically as a function of price.

The 2001 Green River Basin Plan shows that the Basin has more irrigable land than it has available water. Availability of irrigation water, which can be impacted by timing and volume of runoff, location, and seepage and other losses, is the limiting factor in the development of additional irrigated agriculture in the Basin.

The primary crops grown in the Green River Basin are forage crops. Forage production returns are typically not sufficient to justify the costs of new water storage projects or major canal rehabilitation projects without some form of financial assistance. Increased economic returns to irrigated agriculture in the Basin might include diversifying cropping patterns into higher valued crops. For example, small grain production could be increased in some portions of the Basin if a reliable market could be found, as has been done in other areas of Wyoming where barley is grown and sold under long-term contracts to brewers. Another possibility is that hay prices may rise to the point that it would be profitable to export hay from the Basin to other markets, and the possibility that cattle prices may rise significantly in the future.

Due to climatic conditions in the Basin and distance from markets, diversifying cropping patterns away from forage production is not likely to occur on a wide enough scale to warrant significant new water development projects. Most of the Basin above Fontenelle Reservoir is characterized by high elevations, cool nights, and a short growing season, making forage crops the only practical alternative. Grains can be grown in some parts of the Basin. Malting barley is the only grain crop that has been grown in the Basin that has shown significantly higher returns than alfalfa. Increased malt barley production alone would probably not warrant the construction of additional storage projects since it requires less irrigation water than hay crops. Historically, livestock producers have been reluctant to convert to farming, making it even less likely that this change will occur.

Specialty crops, such as alfalfa seed or seed potatoes, could possibly be grown in some of the lower elevation areas of the Basin. Seed alfalfa production is becoming more widespread in Wyoming, where acreage has grown from 3,750 acres in 2002 to 10,315 acres in 2007. Climatic conditions place the Green River Basin at a disadvantage compared to lower elevation areas in the state, such as the Big Horn and North Platte River valleys. Urban development in the western US may be pushing agriculture production to other areas. If population pressures in Arizona, California, and parts of Idaho, Oregon, and Washington displace agricultural production, especially forage production, it may become more valuable as a cash crop for the Basin. As more agricultural land is taken from production in the future, there will be less hay production because it is among the lower valued crops that can be grown in lower elevation areas. The potential for increased forage production in the Green River Basin as a cash crop is real but is likely farther into the future than was anticipated in the 2001 Green River Basin Plan.

Wyoming's top quality alfalfa hay is exported to other states for use in the dairy and equine industries. California dairy producers are expanding their production areas to states such as Idaho, Nebraska, and western Kansas. Dairy producers in the Boise, Idaho area and along the Colorado Front Range are having difficulty securing enough alfalfa locally and are relying upon imports from other states or are relocating to hay producing areas. The Green River Basin is in an attractive location for hay production as a cash crop. Producers have ready access to rail and truck shipping facilities and the Basin is capable of producing high quality, low fiber content hay. Alfalfa grown in Wyoming does not have the blister beetle problem common in warmer climates. If future market prices for hay crops are sufficiently high, it could become practical for Green River Basin producers to develop additional supplemental supply storage and expand production of these crops for export markets. There would have to be some reasonable certainty that high prices would be part of a long-term trend and not just a short-term market fluctuation.

Other factors that could create increased demand for irrigation water in the Basin would be a significant and sustained increase in cattle prices and/or an increase in the amount of financial assistance available to producers for reservoir construction and system improvement and rehabilitation.

Since the 2001 Green River Basin Plan was published, cattle prices have increased slightly. For example, the 2001 average price for choice steers in interior Iowa and Minnesota was $72.91 per 100 pounds, compared to $91.53 in 2008 (http://www.extension.iastate.edu/agdm/livestock/pdf/b2-12.pdf). Although U.S. beef consumption has stabilized at around 67 pounds per-capita, the United States Department of Agriculture (USDA) is forecasting a significant increase in exports of U.S. beef due to NAFTA. The top four markets for beef exports are, in order of export volume: Mexico, Canada, Japan and South Korea. Mexico and Canada have moved ahead of Japan and NAFTA is credited with the shift. Demand for high quality beef is expected to increase significantly in the future as the economies of these countries recover from the world wide recession. The 2001 Green River Basin Plan reported that USDA projections of cash returns after expenses in cow-calf enterprises were expected to increase from an annual average of $32.02 per cow in 1999 and 2000 to $47.14 per cow during 2008 and 2009. However, the Livestock Marketing Information Center (LMIC) estimated returns over expenses at a negative $20.00 per cow for 2008. Cow-calf enterprise returns are quite volatile and extrapolation of returns over a significant time frame is questionable.

6.3 MUNICIPAL AND DOMESTIC DEMAND PROJECTIONS

6.3.1 Introduction

Municipal and domestic use projections were estimated by extrapolating current use rates onto population projections for the Green River Basin. These projections rely on the assumption that per capita use of water won't increase over time. Current municipal and domestic water consumption is described in Chapter 5.

6.3.2 Population Projections

This section presents population projections for the communities and rural areas of the Green River Basin for 2005 through 2055 for low, moderate, and high growth planning scenarios. These projections also provide a basis for assessing water-based recreational resource needs.

Current and Projected Population Estimates

Current population estimates for cities and towns in the Basin were taken from the results and extrapolation of the 2000 census. The Division of Economic Analysis of the Wyoming Department of Administration and Information (WDAI) produces estimates of the population of Wyoming's counties, cities, and towns on an annual basis, and projects those estimates into the future. The WDAI forecasts for the year 2005 were used as current population estimates. Because the geographical boundaries of the Green River Basin do not coincide with county lines, the county population estimates were adjusted to reflect only the proportion of each county that lies within the Green River Basin. Based upon the methodology described above, the total 2005 population of Wyoming's Green River Basin is estimated to be 60,284.

This plan used the following three population projection methods:

- U.S. Census Bureau (USCB) projections
- Wyoming Department of Administration and Information (WDAI) projections
- Historical growth projections

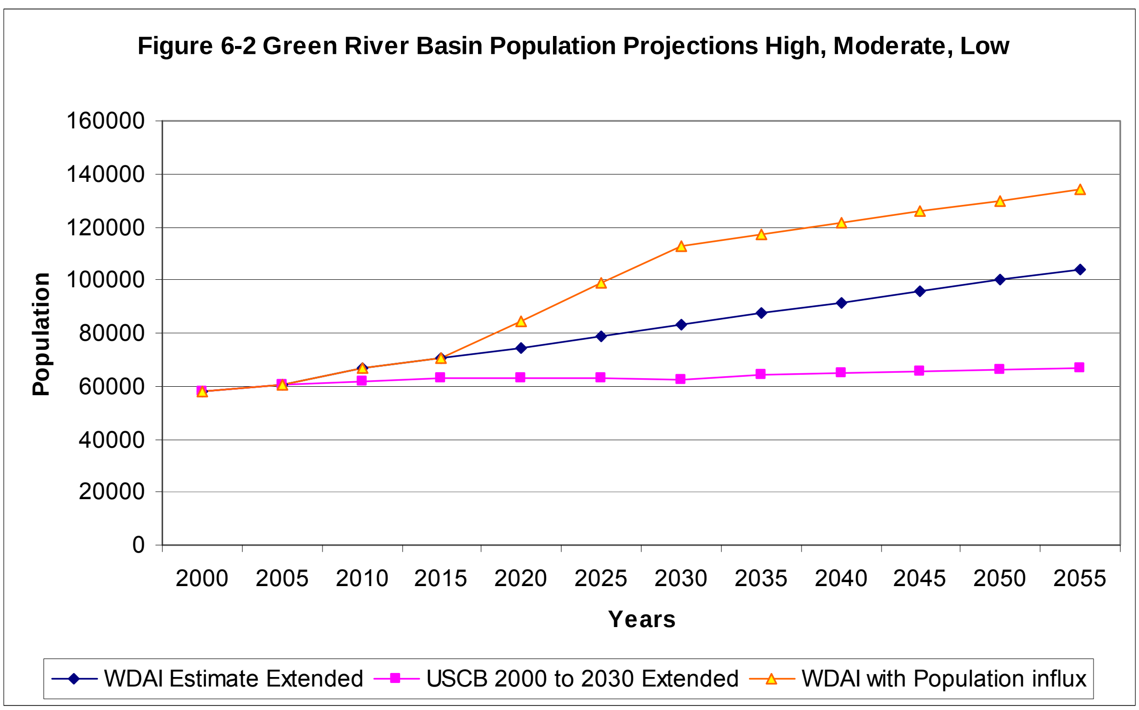
These three methods were used to generate population forecasts through the year 2055 for communities and rural areas. The USCB extended forecasts generally resulted in the smallest population projections, followed by the WDAI projections and the historical growth projections in that order.

Table 6-2 and Figure 6-2 show the 50-year projected populations of the Green River Basin for the high, mid and low scenarios.

Table 6-2 - Green River Basin Low, Moderate, and High Growth Scenario Population Growth

	Year	2000	2005	2010	2015	2020	2025
Total Basin Populations	Low	58,267	60,284	61,762	62,727	63,077	62,849
	Mod	58,267	60,284	67,078	70,552	74,314	78,808
	High	58,267	60,284	67,078	70,552	84,314	98,808
	Year	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Total Basin Populations	Low	62,130	64,051	64,655	65,258	65,861	66,464
	Mod	83,044	87,280	91,517	95,753	99,989	104,225
	High	113,044	117,280	121,517	125,753	129,989	134,225

Source: "Population Projections," tech. memo, WWC Engineering, 2009 (M)



Source: "Population Projections," tech. memo, WWC Engineering, 2009 (M)

United States Census Bureau Projections

The USCB periodically produces population forecasts for each of the 50 states using the cohort survival approach, which is based on fertility and mortality rates. The most recent forecast for the state of Wyoming is a population projection through the year 2030. There is a significant difference between the 2005 population forecasts and the 1999 Series A and Series B population forecasts used in the 2001 Green River Basin Plan population projections for the state of Wyoming. The 2005 projections indicate a very slow future population growth for Wyoming based upon migration patterns and cohort survival estimates. During that period, there was a moderate influx of new residents into some parts of Wyoming from elsewhere in the country and the effects of this migration pattern are apparent in parts of the Green River Basin, namely the Pinedale area. The USCB projections are based upon the assumption that this moderate rate of net in-migration will continue into the future, and that fertility and mortality rates for the state will follow the USCB's middle series projections.

A reasonable set of low growth population projections for the Green River Basin can be developed from the USCB's 2005 projections for Wyoming. The low growth scenario projects a very small Basin-wide population increase over the next 50 years. For this scenario, the current Basin-wide population of 60,284 is projected to increase to only 66,464 by the year 2055.

Wyoming Department of Administration and Information Population Projections

The Division of Economic Analysis of the WDAI produces population forecasts for Wyoming counties, cities, and towns. The county population forecasts are based upon time series data from which growth rates are derived from variables such as population, sales tax collections, and school enrollments. These growth rates are used to forecast individual county population totals, and these county totals are adjusted to make them consistent with state-level population forecasts that incorporate elements of the cohort survival and employment-driven approaches.

WDAI forecasts population only 10 to 15 years into the future because of the uncertainties associated with such projections. WDAI’s most recent projections are through the year 2020 and are higher than past forecasts, a reflection of the increased economic growth that the Basin and many other parts of the state witnessed in the early parts of this decade. A reasonable set of moderate growth rate population projections for the Green River Basin can be derived by using the WDAI’s latest estimates and projections covering the period from 2000 to 2020 and extending those growth rates through the planning period. The moderate growth scenario indicates that Basin-wide population will increase to a total of 104,225 persons by the year 2055, an increase of about 44,000 over current levels. This projection is consistent with the WDAI’s forecast that future net migration patterns will be positive for Wyoming and the Green River Basin.

Historical Growth Projections

A third set of Green River Basin population projections was created by assuming that the area would experience a total population increase during the period from 2015 to 2030 that is of the same magnitude that occurred during the 10-year period from 1970 to 1980. From 1970 to 1980, the population of the Basin grew from 29,574 to 60,255, an increase of 30,681 persons. That increase came about as a result of rapid development of energy and mineral resources in the Basin and the associated influx of workers. If a similar increase in energy and mineral development were to occur again during the planning period, it is possible that the Basin population could increase by another 30,000 persons. If the 30,000-person influx is added to the moderate-growth projection over the 2015 to 2030 time frame it would result in a Basin-wide population of approximately 113,000 persons by year 2030. A reasonable set of high-growth rate population projections for the Green River Basin can then be derived by using these historical growth rates for 2005-2030 period and extending those growth rates through the planning period. Although the probability of the Basin experiencing a return to the boom conditions of the 1970s seems remote under present circumstances, the assumption that it might happen is a reasonable basis for a high-growth scenario for population forecasting. The high-growth scenario results show the Basin's population increasing from 60,284 to 134,225 over the next 50 years.

6.3.3 Municipal and Domestic Use Projections

Municipal Use Projections

Current per capita municipal water consumption is presented in Chapter 5. These rates were applied to the population projection for municipal service areas including incorporated cities, towns, and rural areas serviced by municipal systems. The results of the low, moderate, and high analyses are summarized in Table 6-3.

Table 6-4 displays a comparison of the municipal systems' capacity with demand through the planning horizon for the moderate growth scenario. In most cases, the existing water right capacity is sufficient to cover the projected demand over the planning period, with two exceptions. Under surface water demands, Pinedale's direct flow right will be insufficient to accommodate the moderate growth demands or the high growth demands sometime between 2015 and 2035. However, Pinedale has more than adequate storage water to meet any deficit. Marbleton exhibits similar conditions but does not have storage water to supplement as it is a groundwater supply system. The opportunity to drill more wells and expand their supply may exist.

The City of Cheyenne diverts water from the headwaters of the Little Snake River for municipal use exchange purposes. The system and water rights have a capacity of about 22,700 acre-feet per year, and it is expected to be fully utilized during the planning time frame. Table 6-5 shows the projected diversions, assuming diversions would grow from the present amount uniformly to the maximum allowed, over the 50-year period.

Table 6-3 – Municipal Use Projections Summary

Use by Source	Current	2015	2035	2055
	Acre-feet/Year			
Surface Water				
Low Growth	6,578	6,802	6,886	7,058
Moderate Growth	6,578	7,717	9,628	11,596
High Growth	6,578	7,717	12,880	13,965
Groundwater				
Low Growth	884	1,167	1,642	2,170
Moderate Growth	884	1,312	2,238	3,403
High Growth	884	1,312	3,007	4,382

Source: "Municipal Water Use Projections," tech. memo, WWC Engineering, 2009 (N)

Table 6-4 - Comparison of Existing and Projected Use and System Capacity

Supplier	System Capacity	Water Right	Current Demand	2015 Demand	2035 Demand	2055 Demand	Excess Capacity for 2055 Demand
	(AFD = acre-feet per day)						
Surface Water							
Baggs	1.33	1.24	0.08	0.08	0.073	0.059	1.27
Bridger Valley JPB	12.10	15.10	1.15	1.22	1.25	1.17	10.93
Dixon	0.97	0.97	0.07	0.07	0.07	0.05	0.92
Granger	3.09	13.01	0.05	0.06	0.07	0.07	3.02
GR/RS/SC JPB[1]	97.00	79.30	13.86	15.60	17.57	19.01	77.99
K-D JPB[2]	12.83	17.07	0.82	1.11	1.49	1.89	10.94
LaBarge	1.77	2.64	0.41	0.51	0.67	0.86	0.91
Pinedale	44.20	11.48	1.59	2.49	5.19	8.65	35.55
Groundwater							
Bairoil	3.05	0.41	0.10	0.12	0.13	0.14	2.91
Big Piney	2.65	3.76	0.13	0.19	0.34	0.53	2.12
Marbleton	2.20	4.57	1.96	3.01	5.34	8.29	-6.09
Opal	0.41	0.46	0.05	0.06	0.08	0.10	0.31
Superior	1.60	5.57	0.11	0.12	0.14	0.15	1.45
Wamsutter	3.09	1.51	0.08	0.09	0.1	0.11	2.98

[1]GR/RS/SC JPB - Green River, Rock Springs Sweetwater County Joint Powers Board.

[2]K-D JPB - Kemmerer Diamondville Joint Powers Board.

Source: "Municipal Water Use Projections," tech. memo, WWC Engineering, 2009 (N)

Table 6-5 - City of Cheyenne Diversion Projections

	Year			
	2005	2015	2035	2055
	Acre-Feet			
Annual Diversion	15,308	16,560	19,390	22,700

Source: "Municipal Water Use Projections," tech. memo, WWC Engineering, 2009 (N)

Domestic Use Projections

The Basin's rural population was estimated in Chapter 3 as the difference between the total Basin populations and the populace residing in established cities and towns served by municipal systems. Table 6-6 summarizes domestic use projections calculated in this manner.

Rural domestic independently supplied water use projections may be impacted by decisions of the Basin municipalities. The projections are extensions of historic trends; if the municipalities change their annexation policies or move toward supplying adjacent rural areas, these projections could diminish somewhat. However, during times of fast growth, it is much quicker for people to secure a well driller and provide for their own water supply rather than wait for a municipality to extend its infrastructure to supply them.

Table 6-6 - Domestic Use Projection Summary

	Current	Low Level Growth			Moderate Level Growth			High Level Growth		
	2005	2015	2035	2055	2015	2035	2055	2015	2035	2055
Indepentently Supplied Rural Population	12,066	13,135	14,761	16,733	14,314	19,316	24,908	14,314	26,171	33,297
	Acre-Feet per Year									
Independently Supplied Rural Domestic Water Use @ 150 gpcpd	2,027	2,207	2,480	2,811	2,405	3,246	4,185	2,405	4,397	5,595
Independently Supplied Rural Domestic Water Use @ 300 gpcpd	4,055	4,414	4,961	5,623	4,810	6,491	8,370	4,810	8,795	11,189

Source: "Domestic Water Use Projections," tech memo, WWC Engineering, 2009 (O)
Note: gpcpd = gallons per capita per day

6.4 INDUSTRIAL DEMAND PROJECTIONS

This section presents projections of industrial water needs in the Green River Basin for the period 2005 to 2055. These projections provide a basis for gaging the adequacy of current surface water and groundwater supplies in the Basin to meet potential future industrial needs. The future growth prospects of the significant water using industries in the Basin are presented in low, moderate, and high growth projections of future water use.

6.4.1 Future Electric Power Production

Two coal-fired electric power plants are located in the Green River Basin; the Jim Bridger Power Plant and the Naughton Power Plant, both owned and operated by PacifiCorp. Reported diversions from both power plants in 2006 were 39,714 acre-feet, which is less than the 47,820 acre-feet estimated in the 2001 plan. The amount used varies from year to year, which can be attributed to fluctuating generation load on the plant as well as weather variations. The Jim Bridger Power Plant near Point of Rocks, east of Rock Springs, was originally designed for up to six coal-fired generating units, although only four 500-megawatt units have been installed. The addition of generation resources at Jim Bridger remains a potential next step to increase regional power, however, no definitive plans are currently in place. Coal and water requirements at the Naughton facility are assumed to remain constant at current levels.

Currently, electric power generation makes up 68 percent of the total industrial water use in the Green River Basin. Future water needs for electric power production will be influenced by regulation of the industry and response to environmental issues concerning the discharge of carbon and its contribution to potential global warming. Development of renewable energy sources such as wind powered generation has been prioritized above development of fossil fuel powered generation for the near term. However, many experts predict that coal-fired or other thermal generating capability will need to be developed to insure a consistent supply of low-cost power when renewable power generation is unable to keep up with growth in base load demand.

Large industrial power users may develop co-generation facilities to meet their own needs and sell excess power to retail consumers. There is already evidence of this in the Basin as four of the five trona plants have onsite electrical generation capability. Regulations regarding emission of greenhouse gases are expected make it difficult to build coal-fired power plants or even operate existing plants in the future. In the face of such developments, electric utilities are reluctant to make large investments in new generating facilities in the Green River Basin. Transmission has been considered a roadblock to developing new generating capacity in the Basin. However, PacifiCorp has indicated in their latest Integrated Resource Plan (IRP) that they intend to invest $4 billion in new transmission facilities over the next ten years. This action would tend to indicate an increased potential for new generation development; however, the IRP shows relatively flat demand for the next ten years. Increased transmission capability coupled with increased wind energy generation will tend to push new thermal base load generation farther into the future. However, there will be a need for peaking resources that provide grid support to back up wind.

Projections of future water needs for electric power generation are presented in Table 6-7 for high, moderate, and low growth scenarios. High and moderate-growth scenarios assume the transmission bottleneck out of Wyoming will be eliminated and thus encourage the construction of additional electrical generating capacity.

Table 6-7 - Projected Electrical Power Generation Industrial Water Use

Electric Power Industry	Consumptive Use Acre-Feet/Year			
	2005	2015	2035	2055
Low Growth	39,700	41,600	45,600	50,000
Moderate Growth	39,700	52,300	65,000	65,000
High Growth	39,700	52,300	75,100	115,000

Note: Maximum historical uses at PacificCorp are 47,500 AC-FT with Naughton at 11,500 AC-FT and Bridger at 36,000 AC-FT
Source: "Industrial Water Use Projections," tech. memo, WWC Engineering, 2009 (P)

High Growth Scenario

The high-growth scenario for electrical energy production is based upon the reasonable possibility that high energy prices and/or a disruption of oil imports into the U.S. will stimulate construction of additional electric generating capacity in the Basin. It is also assumed that PacifiCorp's planned $4 billion investment in transmission over the next ten years plus actions by the State of Wyoming and/or the Federal Energy Regulatory Commission will solve the transmission bottleneck out of Wyoming and thus encourage the construction of additional electrical generating capacity in the Basin. The Jim Bridger and Naughton Power Plants have been running at nearly full capacity in recent years, and expanding power production at either facility would require significant capital investments in both generation and transmission facilities.

The logical location for a moderate expansion of generating capacity is the Jim Bridger Power Plant according to PacifiCorp engineers. One conceivable expansion of new resources would be 1800-megawatts of natural gas fired combined cycle generation and 900 megawatts of natural gas fired simple cycle generation. The likely form of new generation in the basin will be natural gas fired combined cycle technology and simple cycle gas turbines or reciprocating engines. It is estimated a 600-megawatt natural gas-fired plant, assuming a water cooled design will require approximately 4,500 acre-feet per year. A nominal 300-megawatt simple cycle plant based on aero derivative gas turbines would use approximately 750 acre-feet per year. The Jim Bridger Power Plant could be expanded by adding two 750-megawatt coal-fired generating units. Cooling water for this expansion would be supplied from a 50-cfs direct flow water right from the Green River. The 750-megawatt units would each consume about 12,300 acre-feet per year. The present plan is to develop one 750-megawatt unit in the next ten years and the second 750-megawatt unit over the next 30 years. However, there are currently no definitive plans to further develop the Jim Bridger Power Plant.

The high-growth scenario assumes that in addition to a 1,500-megawatt expansion of the Jim Bridger Power Plant, a new 3,000-megawatt coal-fired generating facility will be built in the vicinity of coal deposits near Creston Junction, utilizing cooling water piped from the Green River. The Little Snake River would also be a potential source of water for such a plant. However, the lack of storage facilities for industrial water in the Little Snake River Basin makes the Green River, with its already developed storage water in Fontenelle Reservoir and Flaming Gorge Reservoir, a more likely source of water for future power production.

The addition of 4,500 megawatts of generating capacity over the next 50 years would increase total water use for power production to 115,000 acre-feet annually. This figure represents nearly a threefold increase over current utilization levels.

Medium Scenario

The medium-growth scenario, like the high-growth scenario, assumes that power transmission facilities will be constructed and additional coal-fired power plants can be built, either by resolution of the greenhouse gas controversy or with the advent of carbon capture and storage technology. Under this scenario the expansion of the Jim Bridger power plant would proceed as described under the high-growth scenario, but the new generating facilities at Creston Junction would not be built.

The moderate growth scenario for electric power production projects a 75 percent increase in power generation and associated coal production and water requirements for the Jim Bridger Power Plant over the next 30 years. Total water use for the moderate-growth scenario is projected to grow to approximately 52,300 acre-feet annually by the year 2015 and to approximately 65,000 acre-feet annually by 2035. Power generation is then projected to remain stable for the next 20 years over the remainder of the planning period to 2055.

Low Scenario

The low-growth scenario projects current levels of water consumption for power generation to remain relatively constant over the next 50 years. The low-growth scenario is based upon the assumption that any additional power needs in the western U.S. over the next 50 years will be met by the construction of new renewable energy generating facilities such as the new wind generation planned at the Jim Bridger Plant site. The PacifiCorp IRP indicates 900 megawatts of wind generation capacity planned for their Eastern Division (Wyoming, Idaho, and Utah). Another potential is that the nuclear plant planned for Idaho and presently shelved will be constructed and will take a portion of the load in the Northwest. As a result, water requirements for power generation in the Basin will remain at or near current levels over the planning period. This use is assumed to level out at about 50,000 acre-feet annually.

6.4.2 Coal, Uranium, and Miscellaneous Mining

Coal

In the Green River Basin, coal is produced to supply the two coal-fired electric generation plants. The coal mines in the Basin use water mainly for drinking water, sanitation, dust control, equipment washing and mine reclamation activities. These uses are supplied from groundwater at the mines. The three largest mines are the Black Butte and Bridger Mines that supply coal to the Jim Bridger Power Plant and the Pittsburg-Midway Mine that supplies the Naughton Power Plant. For the high and medium growth scenarios, coal production will need to be expanded to supply the increased power generation. The groundwater used by these mines does not directly impact surface water flows, and needs have not been projected into the future.

Uranium

The Kennecott Uranium Company also has a number of groundwater permits for its inactive mine and processing facility in the Great Divide Basin near Rawlins. When it was operational, the mine used well water in a process solution for extracting uranium from ore. Given current energy prices and the current interest in uranium development, the prospects for uranium production are greatly improved from the situation that existed in the 2001 Green River Basin Plan. The most likely uranium mining prospects in the Basin are in the northeast part of the Great Divide Basin. Employee and associated population impacts will likely occur out of the Basin in Rawlins or possibly in Jeffrey City, both in the North Platte Basin.

Miscellaneous Mining

Small mining operations, including aggregate, sand and gravel mining operations, exist in the Basin but they use small amounts of water and are not significant factors in any of the growth scenarios.

6.4.3 Oil and Gas Production and Refining

The oil and gas industry is an economically important industry in the Green River Basin, although water requirements are generally small, utilize mostly groundwater and spread over a large geographic area. Water is used to create mud during drilling and can be used for waterflooding operations. The Bureau of Land Management (BLM) National Environmental Policy Act (NEPA) documents issued since 2000 have identified over 20,000 new wells in addition to the 1,725 existing or producing oil and gas wells estimated in 2000. This number includes oil, natural gas and coalbed natural gas wells. Both oil and natural gas production increased significantly in Sublette and Sweetwater Counties through 2005 while the other Basin counties showed stable or slight declines in production.

Conventional natural gas processing facilities in the Basin also use groundwater, but typically in relatively small amounts. For example, the Exxon Shute Creek Plant has two wells permitted for 100 gpm each and a small direct flow surface water permit (0.134 cfs). In the larger picture of industrial water uses in the Basin, groundwater uses for natural gas processing are relatively small and future needs have not been projected.

6.4.4 Coalbed Methane Natural Gas (CBNG) Production

There is a potential for CBNG development to impact groundwater resources in the Basin over the next 50 years. CBNG development in the Green River Basin is not a major consumptive user of groundwater resources, as the produced groundwater is a by-product of gas production and is most often reinjected. Water is pumped to relieve pressure in coal seams so that the gas can flow to the well and be captured at the surface. The BLM has approved the Atlantic Rim CBNG project that allows up to 1,800 new CBNG wells and 200 conventional oil and gas wells in the area. The Atlantic Rim project area encompasses 270,000 acres in Carbon County, an area that averages 10 miles wide and stretches approximately 40 miles from near Rawlins to near Baggs. The water produced by these wells will likely have a water-to-gas ratio of 4 to 5 barrels of water (Bbls) per thousand cubic feet (MCF) of gas. The water-to-gas ratio is expected to decrease over time as more wells are drilled and pumped. The Atlantic Rim project is projected to yield 1.35 trillion cubic feet (TCF) of gas. The resulting water production would be over 500,000 acre-feet over the life of the project based on a water-to-gas ratio of 3 Bbls/MCF. Other areas of development are in the planning stages in the Basin as well and they would no doubt produce significant volumes of water.

6.4.5 Coal Conversion Facilities

There are currently no coal conversion facilities present or planned in the Green River Basin.

6.4.6 Soda Ash Production

The trona patch west of Green River, Wyoming is the site of five industrial facilities that mine and convert trona to soda ash, an industrial product used in manufacturing glass, detergents, baking soda, and several other industrial and consumer products. As a group, these five facilities mined 19.5 million tons of trona and produced approximately 10.53 million tons of soda ash in 2005. The soda ash industry consumptively used about 16,400 acre-feet of water from the Green River during 2005-2006 water year. Future growth in soda ash production in the Basin will be largely dependent upon export markets. Domestic consumption has been relatively stable in recent years and is expected to grow by only 0.5 percent annually for the foreseeable future. The glass container market is one of the largest consumers of soda ash in the U.S.; the recent increases in oil prices and the resultant impact on the price of plastics could result in increased demand in the glass container market and a slightly increased consumption of soda ash.

Foreign demand for soda ash, especially in developing countries, is expected to increase at a more rapid rate than in the U.S. over the next 50 years. The increased use of glass containers in foreign markets is expected to translate into increased demand for U.S. soda ash because the U.S. has the world's largest deposits of trona and is the lowest-cost producer of soda ash. The near term growth is forecast to be between 2.0 percent and 2.5 percent per year for the next several years.

Three scenarios for future water needs for the Green River Basin's soda ash industry are described below. Table 6-8 summarizes the projected water use by the trona and soda ash industry.

Table 6-8 - Projected Soda Ash Industrial Water Use

Soda Ash Industry	Consumptive Use Acre-Feet/Year			
	2005	2015	2035	2055
Low Growth	16,400	18,600	23,900	30,800
Moderate Growth	16,400	24,200	34,236	48,500
High Growth	16,400	26,400	44,500	71,200

Source: "Industrial Water Use Projections," tech. memo, WWC Engineering, 2009 (P)

High Scenario

The high-growth scenario for soda ash production in the Basin projects increasing efficiencies in production and transportation through solution mining and competition in rail transportation of the finished product. In addition, this scenario projects the possibility of structural changes in some overseas markets that will result from falling tariffs and the elimination of certain other trade barriers. If trade barriers to U.S. exports of soda ash are gradually lowered or eliminated over the next 50 years, Wyoming producers could benefit enormously because they have a competitive advantage with respect to production costs that few other suppliers can equal. The high growth-scenario for Wyoming producers is based upon the assumption that they could reasonably capture one-third of the total world market of 87.9 million tons by the year 2055.

Assuming that domestic production will grow at 1 percent annually, and that exports will grow to one-third of foreign consumption by the year 2055, total estimated soda ash production in the Basin would be 38.97 million tons in 50 years, an increase of 28.44 million tons over current production levels. Assuming that 50 percent of the increased production comes from solution mining (750 gallons per ton) and 50 percent from conventional processes (507 gallons per ton), the increase in annual water requirements for the industry by the year 2055 will be about 54,800 acre-feet. Total water requirements for the industry would be about 71,200 acre-feet annually, an increase of 235 percent over current levels.

Medium Scenario

The moderate-growth scenario projects the reasonably foreseeable possibility that producers will be able to achieve an additional competitive advantage in the export marketplace through reductions in rail transportation costs and the implementation of solution mining for a portion of their future production. The construction of a new rail line would introduce competition into the transportation arena for the first time, and could be expected to reduce the delivered cost of Wyoming soda ash in overseas markets. The implementation of solution mining on a limited scale should also have some cost reduction implications that would give Wyoming soda ash an additional competitive advantage in overseas markets.

Foreign soda ash consumption in 2005 is estimated to be roughly 28.9 million tons annually, of which approximately 18 percent is supplied by Wyoming producers. If foreign consumption increases at the projected rate of 2.25 percent annually, it will reach 87.9 million tons by the year 2055. Wyoming producers could reasonably expect to increase their share of foreign market penetration from 18 to 20 percent as a result of efficiencies described above, meaning that total foreign sales would approach 17.6 million tons annually by the year 2055. Assuming that domestic sales continue to grow at the projected rate of 0.5 percent, total soda ash production would be 25.15 million tons by the year 2055, an increase of 14.62 million tons over current output levels.

The water requirements associated with this scenario are difficult to estimate because of the assumption that solution mining would be employed for a portion of future production. Only one of the Basin's current soda ash producers has production experience with solution mining, and good estimates of historical water utilization are not available. Potential improvements in the process, such as the use of directional drilling techniques, may make future production more water-efficient than past efforts. For purposes of estimating water requirements for this scenario it was assumed that 50 percent of future production increases would come from solution mining and that solution-mining technique would require 750 gallons of water per ton of soda ash produced. Based upon these assumptions, the consumptive use of water by the soda ash industry in the Basin would grow by about 32,000 acre-feet annually by the year 2055 to a total of about 48,500 acre-feet. This figure represents almost a 200 percent increase over current water consumption levels.

Low Scenario

The low-growth scenario for soda ash production assumes no significant changes in the structure of domestic or international markets for soda ash over the 50 year planning period, and no significant changes in production and transportation costs for Wyoming producers. Under these conditions, Green River Basin producers would be expected to maintain their current shares of both domestic and international markets, and their production would be expected to grow roughly in proportion to growth in world consumption.

The overall future growth rate for soda ash production in the Basin is projected to be 1.27 percent annually for the low growth scenario. In 2005 and 2006 the total Green River Basin production of soda ash was estimated at about 10.53 million short tons. At a 1.27 percent annual growth rate, soda ash production in the Basin will grow from 10.53

million short tons in 2005 to 19.8 million short tons by the year 2055. The production increase of 9.26 million short tons annually will require an estimated 4.695 billion gallons of additional water annually, the equivalent of approximately 14,400 acre-feet. That increase would bring total consumptive use up to about 30,800 acre-feet by the year 2055, an increase of 88 percent over current levels.

6.4.7 Miscellaneous Industry

Miscellaneous industry uses of water include fertilizer, hydroelectric and wind generation plants.

Simplot Phosphates manufactures phosphate fertilizer in a plant near Rock Springs. This plant's current average consumptive use is about 600 acre-feet of water annually, which is purchased from the Green River/ Rock Springs/ Sweetwater County Joint Powers Board System. An expansion of production at this facility is probable over the next 50 years under all three growth scenarios.

For purposes of projecting future water needs, the low-growth scenario for this facility assumes that water needs over the 50 year planning horizon would increase to about 1,500 gallons per minute on an average annual basis. Under this scenario the plant would be using about 2,400 acre-feet per year in 2055.

For the moderate-growth scenario, consumptive use is projected to increase to 10,000 acre-feet annually by the year 2055. This scenario assumes that the plant will expand and use its complete contract allocation from Fontenelle Reservoir over the 50 year period. During the first 30 years water would be conveyed from Fontenelle Reservoir to the city of Green River via the river; however, due to the conveyance loss assigned to transporting the water, a pipeline would be constructed from Fontenelle Reservoir directly to the plant after year 2035.

For the high-growth scenario, consumptive use is projected to increase to over 16,000 acre-feet annually by the year 2055. This scenario assumes that the 10,000 acre-foot contract from Fontenelle would be fully utilized plus an additional 3,000 acre-feet from the Joint Powers Board and another 3,000 plus acre-feet either from the Joint Powers Board or from Fontenelle Reservoir. This scenario also assumes that a pipeline would be constructed directly to the reservoir.

Table 6-9 shows the projected industrial water use by the phosphate fertilizer plant at Rock Springs under the three growth scenarios. Hydroelectric and wind power plants generally do not consume significant amounts of water and thus growth of these industries over the 50 year planning period is insignificant.

Table 6-9 - Phosphate Fertilizer Plant Water Use Projections

Scenario	Consumptive Use Acre-feet per Year			
	2005	2015	2035	2055
Low Growth	605	800	1,400	2,400
Moderate Growth	605	4,800	7,500	10,000
High Growth	605	7,700	12,000	16,100

Source: "Industrial Water Use Projections," tech. memo, WWC Engineering, 2009 (P)

6.4.8 Industrial Summary

Industrial water use projections for the Green River Basin described above focus on existing industries and their future water needs. The potential for new industries to locate in the Basin and use available water resources also merits discussion. According to the USCB, four industry groups account for over 95 percent of all of the industrial water used in this country each year. These industries are (1) electric power producers, (2) chemical and allied products manufacturers, (3) primary metals producers, and (4) paper and allied products manufacturers. Electric power producers account for about 70 percent of industrial water use in the Green River with trona mining and processing accounting for 29 percent and miscellaneous uses the other 1 percent.

The other two intensive water use industries, primary metals and paper producers, tend to locate near the source of their largest process inputs -- metals and wood respectively. Although the Basin does have a large timber inventory on National Forest lands, recent trends of reduced timber harvests on federal lands in the Western U.S. make the possibility of timber production or paper mills locating in the Basin remote. The authors of this current plan are of the opinion that any new water-intensive industrial developments in the Basin will fall into the electric power generation and/or chemical products categories. Further, we speculate that shale oil will become increasingly produced in the basin and that industrial uses of water related to this process will grow. The reader is encouraged to review documents on the subject such as that found at http://ostseis.anl.gov/news/index.cfm#rod.

The possibility remains that new industrial water uses not discussed in this report will develop over the next 50 years, but the nature and extent of such developments is not foreseeable at this time and water requirements for such developments are not included in these projections. A summary of industrial projected water use is displayed in Table 6-10.

Table 6-10 - Summary of Industrial Water Use Projections

Scenario/Industry	Consumptive Use Acre-Feet/Year			
	2005	2015	2035	2055
Low Growth				
Electric power	39,700	41,600	45,600	50,000
Soda ash[1]	16,400	18,600	23,900	30,800
Other[2]	700	900	1,500	2,500
Total	**56,800**	**61,100**	**71,000**	**83,300**
Moderate Growth				
Electric power	39,700	52,300	65,000	65,000
Soda ash[1]	16,400	24,200	34,236	48,500
Other[2]	700	4,900	7,600	10,200
Total	**56,800**	**81,400**	**106,400**	**123,700**
High Growth				
Electric power	39,700	52,300	75,100	115,000
Soda ash[1]	16,400	26,400	44,500	71,200
Other[2]	700	7,800	12,100	16,200
Total	**56,800**	**86,500**	**131,700**	**202,400**

[1]Includes related production activities.

[2]Excludes groundwater and small municipal system water users.

Source: “Industrial Water Use Projections,” tech. memo, WWC Engineering, 2009 (P)

6.5 RECREATIONAL DEMAND PROJECTIONS

6.5.1 Introduction

Tourism and recreation create notable consumptive and non-consumptive demands on water in the Green River Basin for golfing, skiing, angling, winter sports, boating, swimming, waterskiing, and enjoying amenities such as creeks, rivers, lakes, reservoirs, and the scenery and habitats that accompany them. Most water-based recreation activities do not directly result in the consumptive use of water, with the exception of irrigation for parks, golf courses, and other landscapes. As described in Chapter 5, little quantitative data are available on recreation use in the Basin. Therefore, the projections in this report are generally descriptive in nature, taking into account a combination of anticipated recreational use trends and population projections.

6.5.2 Future Recreational Demand

In general, population increases and demographic trends in Wyoming, neighboring states, and nationally are anticipated to result in a greater demand for all types of recreation, although the popularity of particular types of recreation will change over time. At the national level, participation in water-related recreational activities is steadily increasing, with the exception of traditional fishing, alpine skiing, and snowmobiling. While no similar data is available for Wyoming or the Green River Basin, it is reasonable to assume that the national declines in those activities would be less apparent in the region due to their overall popularity in Wyoming and in the Basin. If that assumption is correct, one can further assume that all of the top ten water-related recreational activities identified in Chapter 5 in the Green River Basin will continue to increase in participation in the foreseeable future.

The aging of the baby boomer generation in coming years is also anticipated to increase the demand for recreation. The proportion of retirement age persons (above the age of 55) is expected to substantially increase in the next 45 years, from about 22 percent of the population in 2005 to over 50 percent of the population in 2055 (under the moderate scenario). Baby boomer recreationists will generally have more leisure time, a comparably high disposable income, and a greater concern for health and fitness. While many plan to remain active and pursue recreation activities such as hiking, wildlife viewing, skiing, and bicycling, some recreation planners foresee potential shifts in recreational use patterns. For example, recreation that is less physically demanding may increase along with recreation activities that provide higher levels of comfort.

Recent planning documents by the BLM and WGFD have predicted an overall increase in recreation demand in the Green River Basin, as well as the following trends:

- The demand for fishing, floating, camping, off–highway vehicle (OHV) use, and new technology-based recreation is expected to increase.
- Visitation throughout the planning area will continue to increase as resource availability and conditions allow.

- As the population of neighboring states and the local area continues to grow, the desire for less crowded or more remote recreation opportunities will continue to bring more people to the public lands in Wyoming.
- Access for hunting and fishing on private lands will continue to be more restrictive, resulting in heavier use and more crowding at public access sites.

It is difficult to speculate on how population projections will influence recreation demand for the following reasons:

- There is not always a clear, direct correlation between population and recreational use.
- Much of the recreational demand in the Green River Basin is from other parts of Wyoming and from nearby states.
- Recreational uses change based on economic conditions and the availability of time and money for recreation.
- Specific recreational activities fall in and out of favor and popularity over time.

It is reasonable to assume that overall recreational demand trends will generally track with population trends, resulting in growth rates of about 1 to 2 percent annually (for the low-to-high growth scenarios). The average annual growth rates for low, moderate, and high population projections are 0.17, 1.01, and 1.67 percent, respectively. Table 6-11 shows projected recreational activity days based upon these population projection scenarios and the number of recreational activity days surveyed in the 2001 Green River Basin Plan.

Based on the findings and assumptions about recreational trends, population, and demographics described above, the following recreation demand trends are anticipated:

- Overall visitation and recreational use in the Green River Basin will continue to grow and expand.

Table 6-11 - Projected Water-based Recreational Activity Days 2000-2055

Activity	2000 Levels	Low Growth	Moderate Growth	High Growth
	Activity Days			
Stillwater Fishing	485,000	521,860	751,750	974,850
Stream Fishing	300,000	322,800	465,000	603,000
Waterfowl Hunting	10,600	11,406	16,430	21,306

Source: “Future Recreational and Environmental Water Use Projections,” tech. memo, ERO Resources Corporation & WWC Engineering, 2009 (Q)

- Rates of growth will vary based on population trends in Wyoming and in nearby states, but will range between about 1 and 2 percent annually.
- Participation in passive water-based recreation activities, including wildlife viewing and bird watching, will continue to expand and will become increasingly popular among aging populations.
- Demand for fly fishing and float fishing in the Basin will continue to grow, while boating and fishing access will be more competitive.
- Participation in hunting activities will remain steady, while hunting access will become more limited.
- Water demands (e.g., lake levels, river flows) to support all water-based recreation will increase.
- Demand for river access for fishing and boating will increase.
- Any new water development projects will face increasing scrutiny from recreationists and recreation interests and depending on the nature of the project, could provide new or reduced recreational opportunities.
- Any new water projects should consider mitigation measures to accommodate recreational uses, including:
  - Improved boating and fishing access
  - Minimum stream flow or lake level commitments to protect fishing and boating opportunities
  - Measures to protect water-based wildlife habitat
  - Wildlife viewing and interpretive opportunities

Most recreational water uses continue to be non-consumptive, with the exception of alpine skiing (snowmaking) and golf. Although golf is a recreational consumer of water, the water consumed is included in municipal water use projections because golf courses are supplied by municipal systems. Snowmaking takes place at only one ski area near Pinedale and the amount of water consumed in that operation is small. No new water-consuming downhill ski areas are anticipated in the Green River Basin over the planning horizon. Thus, for planning purposes, consumptive water use for the recreational sector is non-consumptive and anticipated to remain so for the planning period.

6.5.3 Adequacy of Existing Resources

According to the WGFD creel survey conducted in the mid-1990s, the Green River Basin and the Bear River Basin combined provide an annual supply of 1,122,800 activity days of lake and reservoir fishing opportunities (Future Recreational and Environmental Water Use Projections, tech. memo, 2009). Almost all of this supply is located in the Green River Basin. Considering that the 2001 utilization rate was approximately 485,000 activity days of use annually and the current rate is estimated to be only slightly larger, it is apparent that there is no shortage of still water angling opportunities in the Green River Basin. This observation is consistent with the fact that the region is endowed with numerous lake and reservoir fisheries ranging from small alpine lakes in the higher elevations of the Bridger-Teton National Forest to Flaming Gorge and Fontenelle Reservoirs in the lower part of the Basin.

Projections of future demands for stillwater fishing opportunities in the Green River Basin ranged from 521,860 to 974,850 activity days annually over the 50-year planning period. The estimated supply of angling days is 1.1 million, and thus the supply of lake and reservoir fishery resources in the Basin should be adequate to meet projected needs for the 50-year planning period. However, the Basin's stream fisheries will come under increasing pressure in the future as Basin population and fishing tourism increases. There is a relatively fixed supply of streams in the Basin that are suitable for maintaining recreational fisheries and any future water development activities in the Basin that would deteriorate existing recreational stream fisheries could have significant negative recreational effects. On the other hand, new reservoir projects in the Basin could generate significant recreational benefits if they include provisions for establishing tailwater fisheries in areas where quality fisheries do not currently exist.

Other economic activities in the Green River Basin could adversely impact recreational uses and opportunities. In general, these impacts usually stem from competing uses for surface water supplies (rivers, streams, and lakes). In some cases, the physical development of water-related facilities could impact the quality or availability of recreation opportunities in that area. Examples of these competing uses include stream diversions for agricultural, industrial, or municipal uses, major reductions or fluctuations in surface water levels on reservoirs, and the development of new water facilities.

6.6 ENVIRONMENTAL DEMAND PROJECTIONS

The availability of water for environmental uses in the Green River Basin is an important component for supporting aquatic, wetland, and riparian habitats and the abundance of fish, waterfowl, and wildlife that rely on these habitats for cover, forage, and reproduction. Environmental water uses are primarily non-consumptive, with many of the benefits to the environment accruing from the natural flow in streams and rivers, as well as in-situ environmental uses occurring coincident and coterminous with the storage, distribution, and use of water for other purposes, including recreation. Anticipated future environmental water needs are based on assumptions about changes in values and priorities related to water-based recreation and environmental resources, and potential conflicts between those priorities and future water needs for agriculture, municipal, industrial and other uses.

Future environmental water demands in the Green River Basin can be anticipated by looking at current values and trends, plans for future environmental projects, and areas that are identified for environmental protection. However, any future projections are somewhat speculative, since environmental water uses will vary based on climate conditions, federal and state species listing status, changes to state and federal laws, and changes in community values and water uses. Most environmental water uses continue to be non-consumptive, with the exception of evaporation from environmental construction such as riparian area improvements, increased diversion and consumption at Seedskadee National Wildlife Refuge, developments in the Little Snake River, and increased enrollment in federal assistance programs such as the Conservation Reserve Program

(CRP), the Wetlands Reserve Program (WRP), and the Wildlife Habitat Incentives Program (WHIP).

Based on the current environmental uses, potential areas of conflict, and overall trends, some of the following can be anticipated regarding future environmental water demands:

- Instream flow and minimum pool designations will persist, and may expand over time in response to protection of resources, changing uses, and public priorities.
- The demand for sufficient water supplies to support wildlife habitat will continue and increase.
- Any new water projects will face increasing scrutiny and demands to protect water-dependent values, particularly fisheries and wildlife habitat.
- Periods of prolonged drought will exacerbate conflicts over environmental uses and priorities.

6.6.1 Instream Flows

The Wyoming Instream Flow Law allows for the maintenance of streamflows to be considered a beneficial use, and allows for unappropriated water to be appropriated to maintain or improve fisheries. Several streams in the Green River Basin have instream flow water rights issued by the Wyoming State Engineer's Office. In addition, there are bypass requirements below several reservoirs in the Green River Basin. Most WGFD identified stream segments are stream segments inhabited by the Colorado River Cutthroat Trout, a sensitive species. The WGFD is also evaluating appropriate instream flows for other reaches. It is likely that instream flow designations will continue to expand in the future as the WGFD identifies areas for protection. Between 2001 and 2005, the number of instream flow sections in the Green River Basin increased from 33 to 35, and this increasing trend is expected to continue over the planning horizon.

6.6.2 Minimum Reservoir Pools

Another environmental water use is the provision of minimum reservoir pools for fish and wildlife purposes. Five reservoirs in the Basin have "fish" or "fish and wildlife" uses listed in their permitting documents; Big Sandy, Boulder, Flaming Gorge, Fontenelle, and High Savery. Of these, only two have a specific amount of storage committed to a minimum pool: Boulder with 1,621 acre-feet and High Savery with 4,955 acre-feet. The WGFD also has identified recommended water surface area for lakes and reservoirs larger than 100 acres that are desirable for supporting game fish populations. Recommended minimum acres of surface area for these reservoirs are not permitted minimum storage rights and are not enforceable. No change in the minimum reservoir pool for these reservoirs is anticipated in the future although given the current federal regulatory environment and the desire of the public to maintain and enhance recreational fisheries in the Basin, it is likely that any additional storage developed in the future will have a portion of its storage devoted to fish and wildlife purposes.

6.6.3 Minimum Releases and Reservoir Bypasses

Only four reservoirs have flow bypasses required by permit. These are Fontenelle Reservoir (50 cfs at the city of Green River), Meeks Cabin Reservoir (10 cfs), Stateline Reservoir (7 cfs), and High Savery Reservoir (10 cfs). The development of additional reservoir storage in the future would likely bring about requests by the WGFD and others for such minimum flow bypass requirements.

6.6.4 Wetlands and Wildlife Habitat

Wildlife habitat exists in wetland and riparian areas on public and private lands throughout the Basin, some of it occurring naturally and some of it as a result of human activity. Wetlands provide significant nesting and breeding habitat for bird populations, microorganisms, plants, reptiles, amphibians, and some mammals. Riparian areas provide an important source of forage, cover, and habitat diversity in arid environments for a variety of wildlife species. Based on existing vegetation mapping, the Green River Basin supports about 383,000 acres of wetlands and about 758,007 acres of riparian habitat. The need for water to support this habitat will continue in the future and is subject to competing water uses. There are several wetland and riparian habitat mitigation or construction projects planned in the Green River Basin over the planning horizon. As an example, the Little Snake River Conservation District has proposed several small reservoirs to provide wildlife, stock and fishery benefits.

6.6.5 Direct Wildlife Consumption

Direct wildlife consumption in the Green River Basin uses about 500 acre-feet annually. This level of consumptive use is projected to remain relatively small and unchanged over the planning period. These uses are not caused or imposed by man and therefore are not included in uses that count towards Wyoming’s compact allocation.

6.7 SUMMARY OF FUTURE WATER DEMAND PROJECTIONS

Table 6-12 presents the projected demands for the water-using sectors for each scenario, and contrasts the projections with those made in 2001. Furthermore, the table provides estimates of how much water remains in Wyoming’s compact allocation.

Table 6-12 - Summary of Projected Surface Water Depletions and Remaining Compact Allocation

Surface Water	AF/YR					
	2001 Basin Plan 30 Yr Projection			2010 Basin Plan 50 Yr Projection		
	Projected Growth Scenario					
	Low	Moderate	High	Low	Moderate	High
Wyoming's Allocation of the Upper Colorado River Water	833,000	833,000	833,000	847,000	847,000	847,000
Total Estimated Depletions	630,900	682,800	766,700	608,295	680,076	784,675
Remaining Compact Allocation	202,100	150,200	66,300	238,705	166,924	62,325

Notes:

Total estimated depletions were prepared using the data from Chapter 6 Tables and the approximations described in the footnotes to Table 7-4.

Wyoming's allocation of the Upper Colorado River Water was estimated by the Wyoming State Engineer's Office, October 1, 2010.

The State can store 120,000 ac-ft of water in Fontenelle Reservoir. The estimate of Remaining Compact Allocation is based on the assumption that the future industrial depletion shown will be met, at least in part, by the State of Wyoming Fontenelle Water Storage account.

6.8 REFERENCES

"Irrigation Water Needs and Demand Projects," tech. memo, WWC Engineering, 2009 (L)

"Population Projections," tech memo, WWC Engineering, 2009 (M)

"Municipal Water Use Projections," tech. memo, WWC Engineering, 2009 (N)

"Domestic Water Use Projections," tech. memo, WWC Engineering, 2009 (O)

"Industrial Water Use Projections," tech. memo, WWC Engineering, 2009 (P)

"Future Recreational and Environmental Water Use Projections," tech. memo, WWC Engineering, 2009 (Q)

Dams and Reservoirs Division, Wyoming Water Development Office, *Unpublished Report*, 2007

7.0 AVAILABILITY

This chapter presents estimates of the availability of surface water and groundwater for future uses.

7.1 SURFACE WATER

7.1.1 Introduction

The following subsections describe the analysis of existing surface water data, creation of spreadsheet-based surface water models, and use of the models' output to estimate water availability. The modeled results described herein denote physically available water over and above existing uses, which is to be distinguished from legal or permitted availability. As projects are proposed in the future, surface water availability will be reduced due to environmental and administrative requirements; lack of physical availability of water for a project is an obvious fatal flaw for any water development. Determining physical availability is the important first step in assessing the viability of any future project.

7.1.2 Methodology

The physically available surface water was determined through the construction and use of a spreadsheet simulation model that calculated water availability based on the physical amount of water present at specific locations of water resource features such as points of diversion, reservoirs, tributary confluences and gages, compact requirements, instream flows, and minimum flows. The determination of available surface water is broken down into the following seven components:

- Compilation of historic streamflow records.
- Study period selection.
- Data extension.
- Estimating natural flow at ungaged model nodes.
- Determining streamflows during wet, normal, and dry years.
- Spreadsheet model development and calibration.
- Determination of physically present surface water.

The *Guidelines for Development of Basin Plans* published by the WWDC in 2001 recommends that for the purposes of the river basin planning process, a hydrologic analysis be conducted for three periods using average dry year conditions, average normal year conditions, and average wet year conditions. Therefore, each hydrologic region in a basinwide model has three associated spreadsheet models representing these three hydrologic conditions. The gaged flows used in the three hydrologic condition spreadsheet models are developed by averaging recorded monthly streamflows to determine groups of years falling into those three hydrologic categories during a consistent period of record. The high and low twenty percentile flow years become the wet model and the dry model, respectively, with the middle 60 percent representing the normal years. The study period has been extended since the 2001 modeling effort, for which the study period was 1971-1998, and thus the new determinations of dry, normal, and wet hydrologic conditions is slightly different.

To determine the study period, historic streamflow records were analyzed for the Green River Basin. In the selection process, major events that would have affected streamflow were considered such as the major construction or alteration of dams that would have major effects on all stream gages located below the dam. These events were minimized to the extent possible and the selected study period for the Green River Basin is 1971-2007 for this basin planning report. The period selected from 1971 through 2007 contains extended periods of dry years including some of the driest years of record as well as periods of normal and wet hydrologic conditions. The selected study period also has the greatest abundance of recorded streamflow data and ditch diversion data and therefore requires less data extrapolation.

7.1.3 Surface Water Model

The purpose of the statewide planning process is to provide decision-makers with current, defensible data to allow them to manage water resources for the benefit of all the state's citizens (Wyoming Framework Water Plan, 2007). Spreadsheet models were developed to determine average monthly streamflow in the Basin during wet, normal, and dry years. The purpose of these models was to validate existing Basin uses, assist in determining the timing and location of water physically available for future development, and help to assess impacts of future water supply alternatives. The WWDC specified that the river basin models be consistent and use software available to the average citizen. Accordingly, Microsoft® Excel was selected as the software to support the spreadsheet modeling effort.

Model Overview

For each Green River sub-basin, three models were developed reflecting each of three hydrologic conditions: dry, normal, and wet year water supply. The spreadsheets each represent one calendar year of flows, on a monthly time step. The modelers relied on historical gage data from 1971 to 2007 to identify the hydrologic conditions for each year in the study period**.** Streamflow, consumptive use, instream flows, diversions, irrigation returns, and reservoir conditions are the basic input data to the model. For all of this data, average values drawn from the dry, normal, or wet subsets of the study period were computed for use in the spreadsheets. The models do not explicitly account for water rights, appropriations, or compact allocations, nor is the model operated based on these legal constraints. It is assumed that the historical data reflect the effects of any limitations that may have been placed upon water users by water rights restrictions.

There are 12 spreadsheet workbooks, one for each of the normal, wet and dry hydrologic conditions for each of the four subbasins:

- Upper Green River Basin from the Green River headwaters to Flaming Gorge
- Blacks Fork River Basin from the Blacks Fork and Smiths Fork headwaters to Flaming Gorge
- Henrys Fork River Basin from the Henrys Fork headwaters to Flaming Gorge
- Little Snake River Basin from the Little Snake headwaters to the USGS stream gaging station on the Little Snake River near Lily, CO.

Model Structure and Components

Each of the Green River sub-basin models is a workbook consisting of numerous individual pages (worksheets). Each worksheet is a component of the model and completes a specific task required for execution of the model. There are five basic types of worksheets:

- **Navigation Worksheets:** are Graphical User Interfaces (GUIs) containing buttons used to move within the workbook.
- **Input Worksheets:** are raw data entry worksheets (USGS gage data or headwater inflow data, diversion data, etc.).
- **Computation Worksheets**: compute various components of the model (gains/losses).
- **Reach/Node Worksheets:** calculate the water budget node by node.
- **Results Worksheets**: tabulate and present the model output.

To mathematically represent each sub-basin system, the Basin river system was divided into reaches based primarily upon the location of major tributary confluences. Each reach was then sub-divided by identifying a series of individual nodes representing diversions, reservoirs, tributary confluences, gages, or other significant water resources features. The resulting network of reaches and nodes is a simplification of the real world which the model represents. Figures 7-1, 7-2, 7-3, and 7-4 are node and reach diagrams for each of the four subbasins: the Upper Green River Basin, Blacks Fork River Basin, Henrys Fork River Basin, and the Little Snake River Basin.

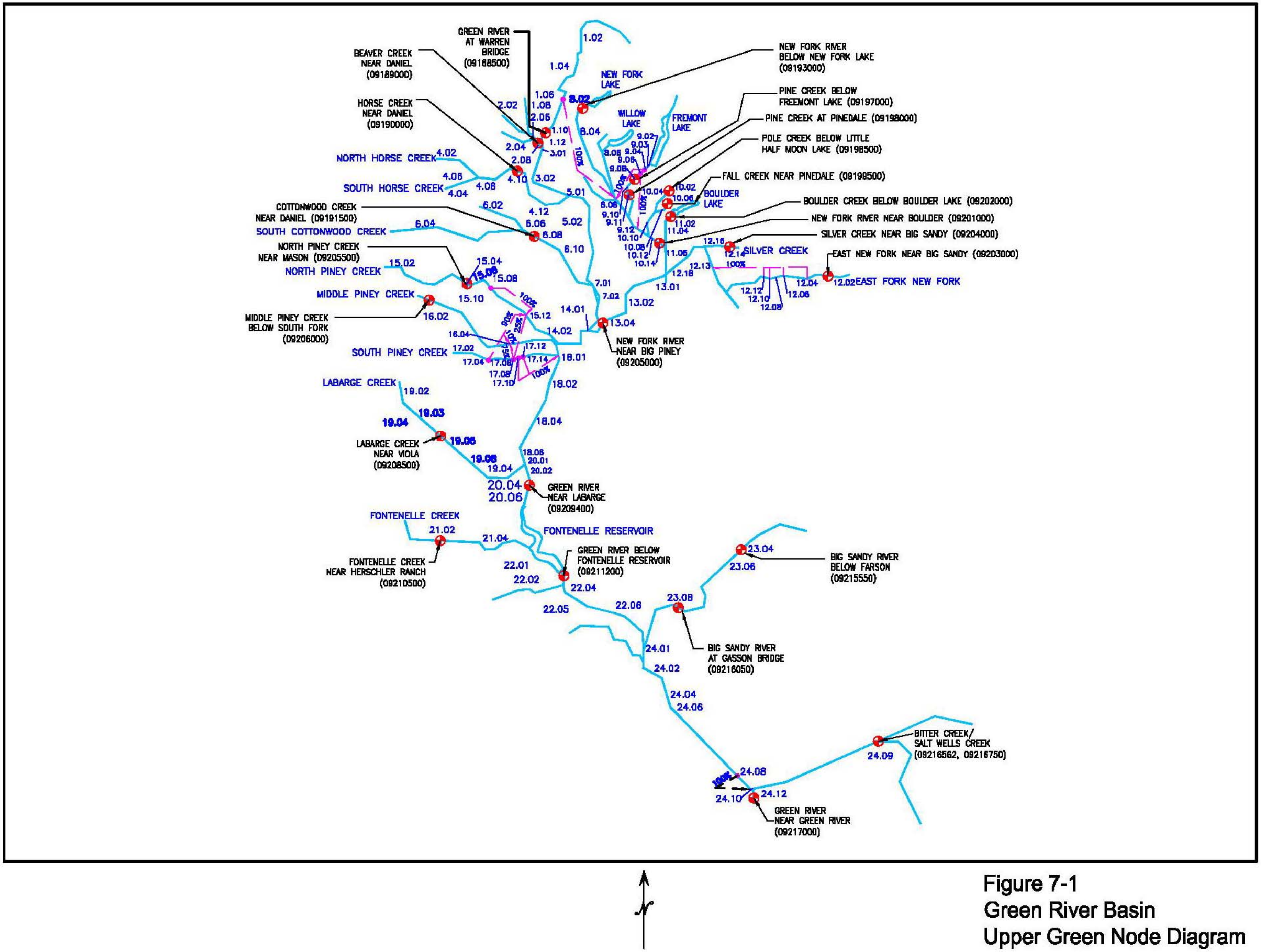


Figure 7-1
Green River Basin
Upper Green Node Diagram

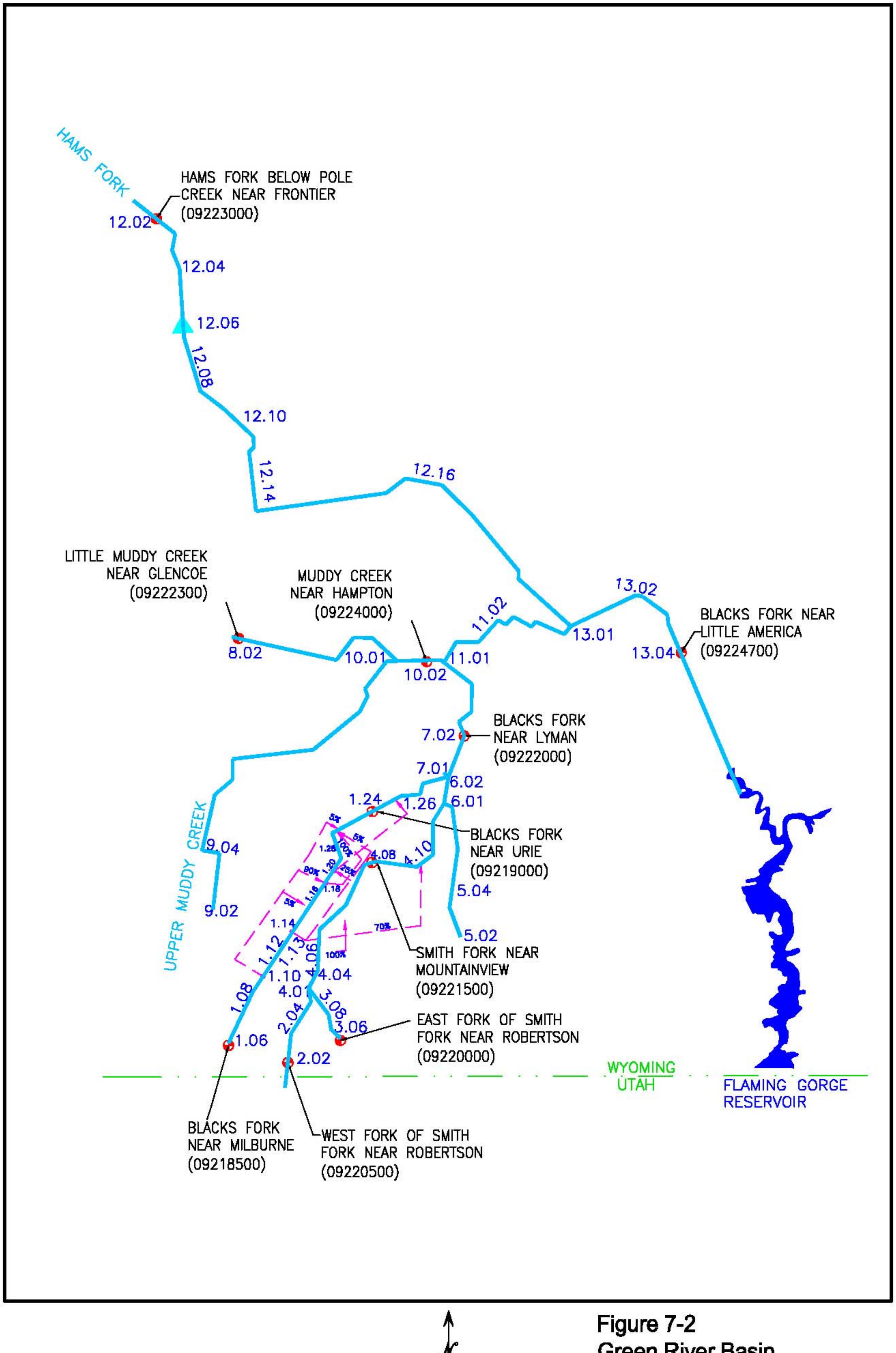


Figure 7-2
Green River Basin
Blacks Fork Node Diagram

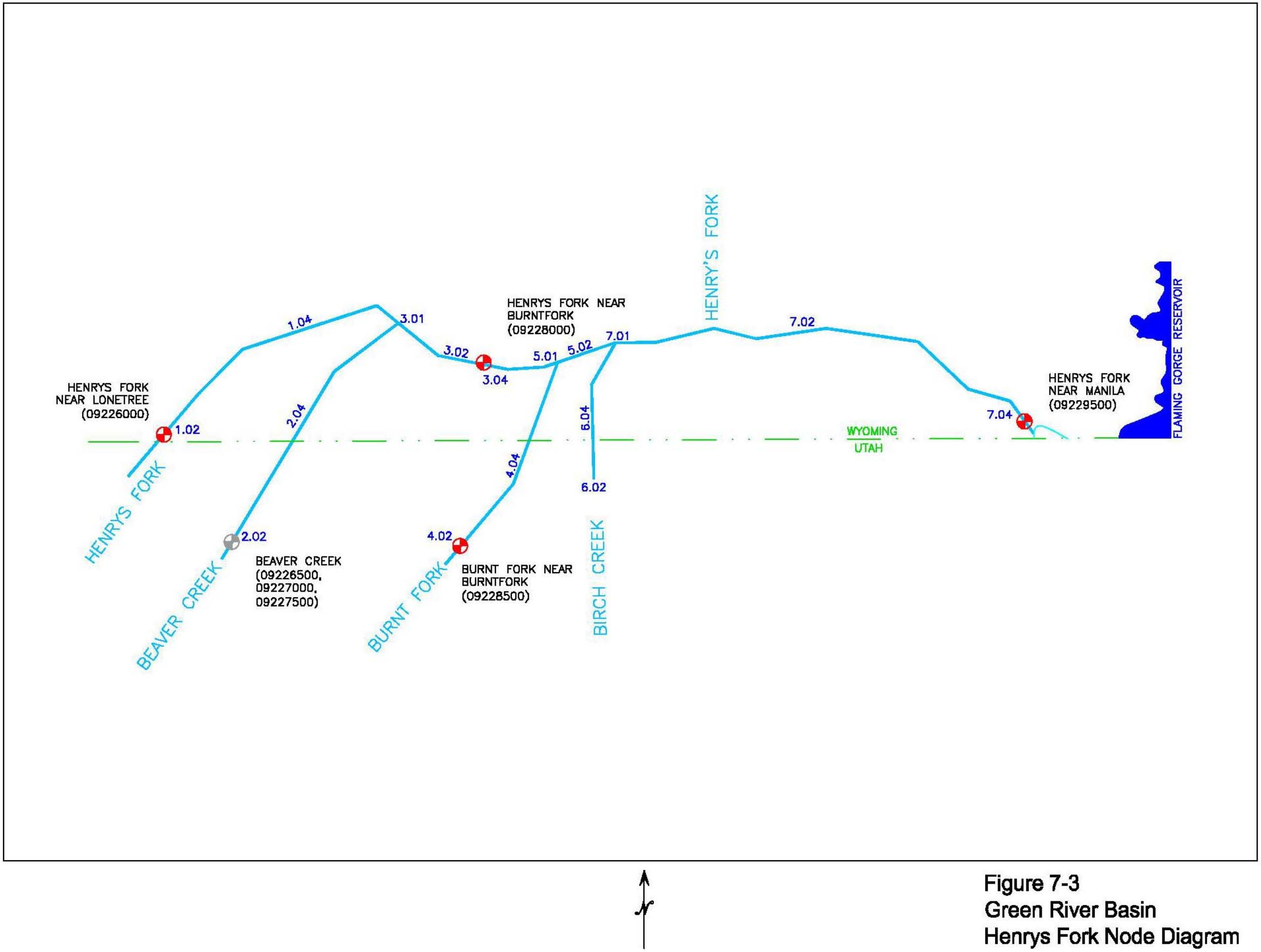


Figure 7-3
Green River Basin
Henrys Fork Node Diagram

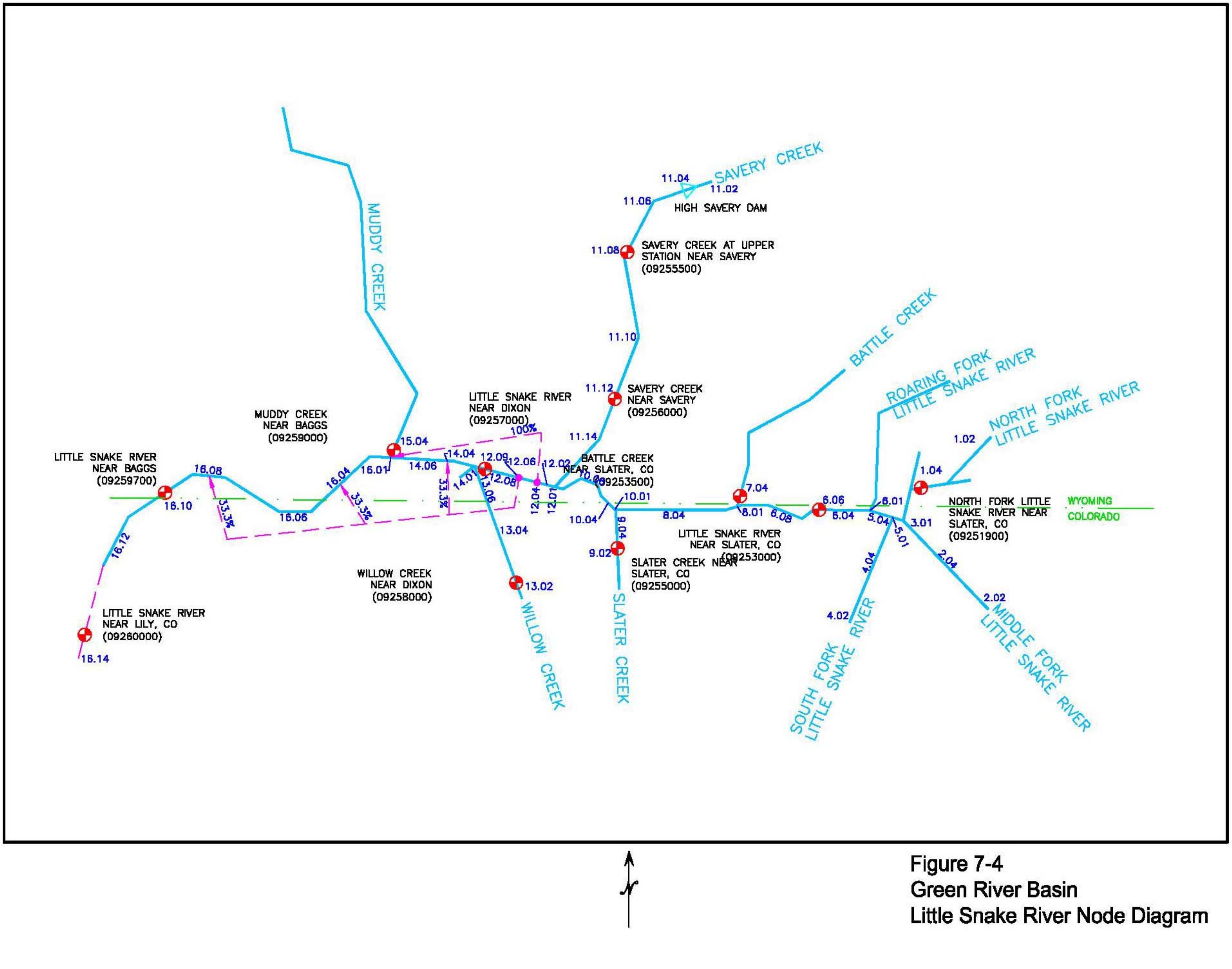


Figure 7-4
Green River Basin
Little Snake River Node Diagram

Stream Gage Data

Monthly stream gage data was obtained primarily from the USGS website and supplemented by the annual SEO hydrographers' reports or U.S. Bureau of Reclamation gage data for each of the stream gages used in the model. Linear regression techniques were used to estimate missing values for the gages that had incomplete records. Once the gages were filled in for the study period, monthly values for dry, normal, and wet conditions were averaged from the dry, normal, or wet years of the study period. The dry, normal, and wet years were determined on a subbasin level from indicator gages that covered the Basin, were relatively free of influence by human activities, and were reasonably complete during the study period. Headwater inflow at several ungaged locations is estimated. The estimated inflows are treated as if they were gaged flows by the model.

Diversion Data

Surface water diversions are made up of agricultural, industrial and municipal diversions. Agricultural use is by far the largest diverter for irrigation purposes. However, industrial and municipal uses also rely on surface water diversions. Agricultural diversions are more sensitive to hydrologic conditions due to the lack of supplemental storage and the model reflects changes in agricultural diversions due to wet, normal, and dry years. Municipal diversions are typically fairly constant despite hydrological conditions and thus were modeled using both depletion values shown in Chapter 5 and historical diversion records. Industrial depletions are also fairly constant and generally 100 percent consumptive. Industrial use values from Chapter 5 were used in the model.

Data on the diversion data sheet are used to calculate ungaged reach gains and losses, and in some cases, inflow at ungaged headwater nodes. They are also used as the diversion demand in the Reach/Node worksheets.

Reach Gain/Loss

The models simulate major diversions and features of the basins, but minor water features such as small tributaries lacking historical records and diversions for small permitted acreages are not explicitly included. Some features are aggregated and modeled, while the effects of many others are lumped together using a modeling construct called "ungaged reach gains and losses." These ungaged gains and losses account for all water in the water budget that is not explicitly named and can reflect ungaged tributaries, groundwater/surface water interactions, lagged return flows associated with structures that divert consumptive use only in the model, or any other process not explicitly or perfectly modeled.

The only imports or exports modeled in the Green River Basin Models are the Cheyenne Stage I and Stage II exports from the upper reaches of the North Fork of the

Little Snake River. Historical records were obtained for the study period and monthly exports were averaged for the dry, normal, and wet years.

7.1.4 Stream Flow Estimates

An output worksheet in each spreadsheet model that summarizes monthly flow is computed at each node to determine the amount of water that flows downstream out of the node and provides the basis of this availability analysis. In general, simulated flow at each node terminus indicates how much water is physically present, but it may not fully reflect flow that is available for future appropriation. This apparently "available flow" may already be appropriated to a downstream user, may be allocated downstream to satisfy compact or decree obligations, may be satisfying an instream flow right, or may result from reservoir storage water being delivered to specific points of diversion downstream. It is important to acknowledge these existing demands when determining developable flow, as distinguished from physically available flow.

To determine how much of the physical supply is actually developable for future uses, physical supply at a node terminus must be reduced to provide for the following circumstances:

- assumed approval of pending instream flow right applications.
- deliveries of storage water.
- Total values must exceed the remaining developable allowance as limited by the Colorado River Compact and Upper Colorado River Basin Compact to have available water.

The flow that is physically present and could be developed for future uses at each point is defined as the minimum of the physical supply value, adjusted to take into account instream flow demands and the adjusted physically present flow at all downstream reaches. In other words, if adjusted physical supply at the node is the limiting value, then all that water can be removed from the stream without impacting either instream demand at this location or downstream appropriators. Thus, water available for future appropriation must be defined first at the most downstream point, with upstream availability calculated in stream order. These calculations were made on a monthly basis with annual availability computed as the sum of monthly available water. Calculating annual availability in this way can yield a different value than applying the same logic to annual flows for each reach; the summation of monthly values is more accurate, reflecting constraints of downstream use on a monthly basis.

The reader should note that this physically available supply adjusted for downstream demands and delivery of storage water is further subject to the Upper Colorado River Basin Compact and the Colorado River Compact limitations.

As virgin flow estimates were not prepared in the Green River Basin, a comparison of present flows to current levels of depletion was made. Table 7-1 shows the flows that were estimated for the average or normal hydrologic condition for the current plan and the 2001 plan; these flow estimates were reduced by the current depletions estimated in Chapter 5. The reduction in streamflow leaving the state since 2001 can be attributed to increased consumptive use, a drier study period, refined availability analysis based on the more accurate node water analysis rather than reach water availability, the inclusion of five instream flow permits rather than just the one that existed in the study area in 2000, and the construction and incorporation of High Savery Reservoir into the spreadsheet.

Table 7-1 - Current Surface Water Availability Estimates Compared with 2001 Plan Estimates

	2001 GRBP	2010 GRBP	Difference	% Difference
	Acre-Feet / Year			
Blacks Fork				
Dry	101,000	67,000	-34,000	-34%
Normal	299,000	195,000	-34,000	-15%
Wet	422,000	398,000	-24,000	-6%
Henrys Fork				
Dry	23,000	24,000	1,000	4%
Normal	60,000	52,000	-8,000	-13%
Wet	125,000	118,000	-7,000	-6%
Little Snake				
Dry	189,000	177,000	-12,000	-6%
Normal	449,000	407,000	-42,000	-9%
Wet	665,000	642,000	-23,000	-3%
Upper Green				
Dry	620,000	595,000	-25,000	-4%
Normal	1,269,000	1,138,000	-131,000	-10%
Wet	1,924,000	1,806,000	-118,000	-6%

StateMod Model

As part of this 2010 Green River Basin Plan, StateMod, a general water allocation model, was extended to match the area covered by the spreadsheet model for comparison of the results of the two models and calibration of StateMod. StateMod is a model used to distribute the natural water supply to users according to their demand and the prior appropriation doctrine throughout a specified modeling period. StateMod is fundamentally different from the spreadsheet models in that it steps through each month of the study period, whereas the spreadsheet models reflect three different years that typify normal, wet, and dry conditions. The StateMod model dynamically "decides" where water can be diverted based on characteristics of the diversion or reservoir structures and water rights, whereas the spreadsheet models strictly reflect historical water uses and operations. Underlying hydrologic data is the same for the two models, but the extremes of record are played out in StateMod representation of specific years such as 1977 or 1986, while the spreadsheet model averages the driest and wettest years in with the rest of the lowest/highest 20 percent of years to produce a less extreme hydrology. Lastly, the spreadsheet models depend on irrigation water requirements developed at the University of Wyoming, for the period 1965 through 1990, while the StateMod model uses the modified Blaney-Criddle method in each irrigation season time step, incorporating crop coeffieients that were calibrated to the University of Wyoming datasets. The results of the StateMod model as compared to the spreadsheet model are presented in Table 7-3.

7.1.5 Basin Supply Estimates

The amount of physically available water is depicted in Table 7-2 and Figure 7-5 as the available flow at specific points of the Green River Basin.

Table 4-1 shows the current amount of physically available water less current depletions for the normal, dry and wet hydrologic conditions. This table shows that the Green River Basin has adequate surface water resources to meet its diversion requirements and satisfy the Colorado River and Upper Colorado River Basin Compacts for normal, wet, and dry hydrologic conditions. It is important to note that these margins of available water are smaller than estimated in the 2001 Green River Basin Plan. This change is caused by the difference in annual water availability averages between the two basin plans; since 2001, two thirds of the intervening years have been dry and none have been wet, decreasing the average amount of estimated water availability. Consumptive use has also increased nominally further lessening the margin of available water.

StateMod Model

According to the StateMod model, average annual water availability at the USGS Green River gage is 1,211,000 acre-feet per year. This represents an average for years 1971 through 2006. However, if StateMod results for the normal, wet, and dry study years are averaged, the results can be compared with results from the spreadsheet models relatively well. Table 7-3 shows this comparison.

The greater estimate of flows in the historical diversions scenario is probably most related to spatial distribution of the baseflow gains. Baseflow can be estimated at the stream gages, which provide a “window” to the baseflow. Between these windows, the modeler must estimate where the gain from gage to gage accrues to the stream. If the estimate is incorrect, the modeled diverters may not have access to water that was available historically, and the diversion is shorted. To the extent that the diversion and associated consumption do not occur, extra water “shows up” somewhere downstream.

The crop-based demand scenario produced lower simulated flows at Green River than the historical diversions scenario (although not lower than gaged values for normal and wet years) because the estimated demand can be greater than the historical diversion in any given month, and if there happens to be water available, the simulated diversion will take the water. For example, May and September demand is based on a crop requirement that reflects temperature and precipitation. If a farmer chose not to divert in May because his headgate is still under snow, or in September because he has cut his hay, the model will still divert water at these times. Another source of discrepancy between historical diversion estimates and crop-based demand is related to the absence of information about first and last use of irrigation water for the season. These dates are not typically recorded. If the first diversion rate observation is actually made several weeks into the diversion season, then the estimate of historical diversions does not truly reflect demand. In this case, the crop-based estimate may be closer to reality.

Table 7-2 - Physically Available Flows in the Green River Basin

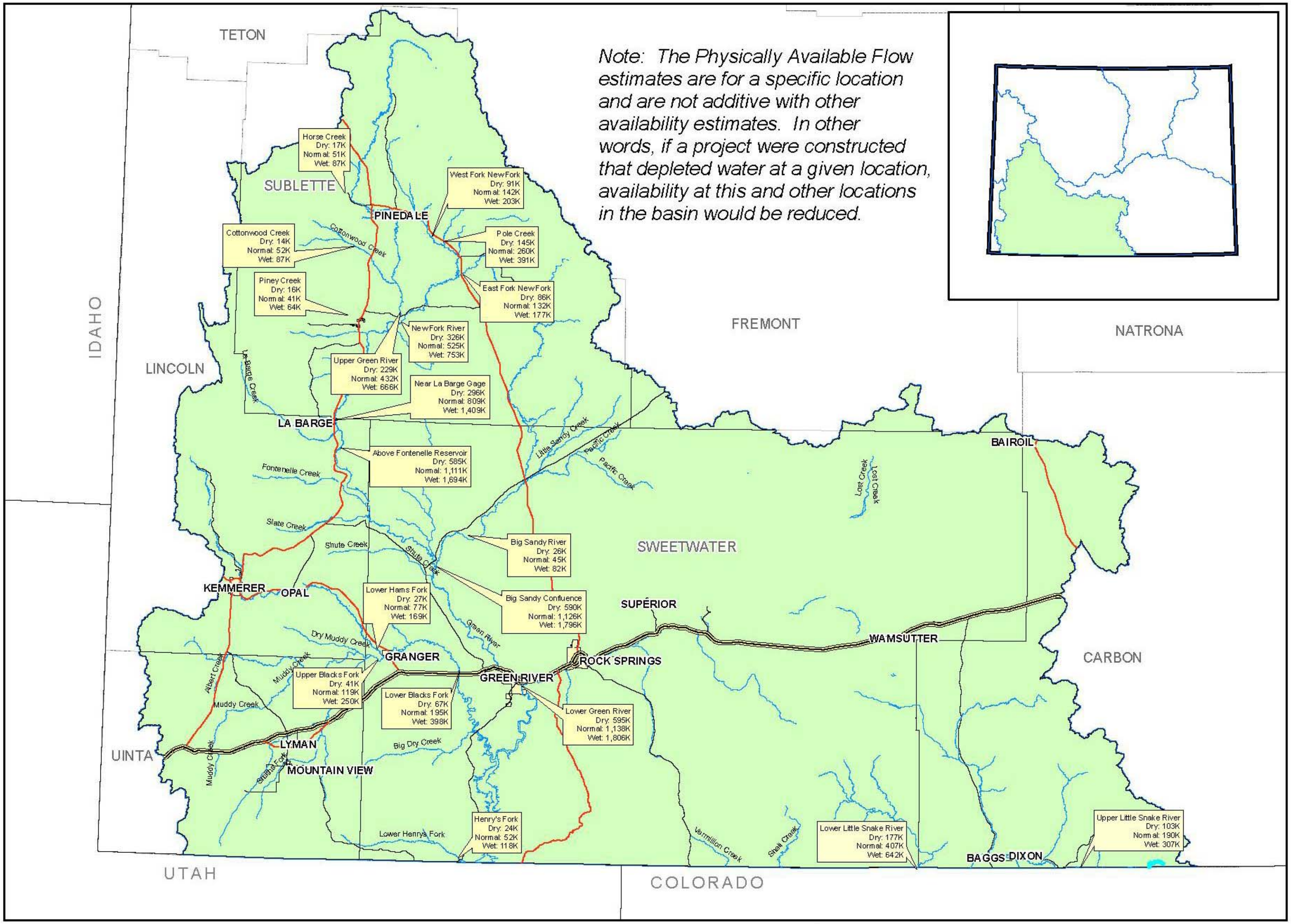
Water Body	Hydrologic Condition		
	Dry	Normal	Wet
	Acre-Feet/Year		
Henrys Fork	23,638	51,809	117,786
Lower Blacks Fork	66,736	195,082	397,706
Lower Hams Fork	27,275	76,696	169,218
Upper Blacks Fork	41,413	118,960	249,913
Upper Little Snake River	103,316	189,759	306,920
Lower Little Snake River	177,321	406,658	641,712
Lower Green River	595,320	1,137,732	1,806,305
Near LaBarge Gage	296,009	808,709	1,408,842
Above Fontenelle Reservoir	584,924	1,110,921	1,693,716
Upper Green River	229,097	432,010	666,489
Big Sandy River	25,813	45,291	82,412
Big Sandy Confluence	589,706	1,126,008	1,796,457
New Fork River	325,886	525,043	753,308
Horse Creek	17,021	51,054	87,034
Cottonwood Creek	13,852	51,659	86,976
West Fork New Fork	91,238	141,983	203,114
Pole Creek	144,863	259,658	391,295
East Fork New Fork	86,377	131,947	176,674
North Piney Creek (below Musselman)	15,904	40,665	63,966

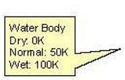
Source: “Available Surface Water Determination,” tech. memo, AECOM, 2010 (T)
Note: Estimates made using spreadsheet model as described in the above referenced technical memo.

Table 7-3 - Water Availability Estimates at the USGS Green River Gage using Spreadsheets and StateMod Models

	Dry	Normal	Wet
	Acre-Feet/Year		
Spreadsheet Result	595,000	1,138,000	1,806,000
StateMod Result (Historical Demand)	601,000	1,179,000	1,835,000
StateMod with Crop-based Demand Result	555,000	1,165,000	1,825,000

Source: “Available Surface Water Determination,” tech. memo, AECOM, 2010 (T)





LEGEND

Physically Available Flow, thousand ac-ft

Figure 7-5
Green River Basin
Physically Available Flows

7.1.6 Future Supply Estimates

The most conservative estimate of water availability for the future is the dry hydrologic condition depleted by the projected use amounts discussed in Chapter 6. The most likely projection scenario for the Green River Basin is the moderate scenario, and those values are used to estimate future depletions here. Table 7-4 shows the flow estimates resulting from the moderate scenario depletions during dry hydrologic conditions. Based upon the estimates shown in Table 7-4, the Green River Basin will still have adequate water supplies under current estimates of Wyoming's compact allocation in the year 2055 to satisfy the Upper Colorado River Basin and Colorado River Compacts. The Green River Basin will have approximately 150,000 to 250,000 acre-feet of unused water under the compacts and assuming that water augmentation and conservation projects will most likely be more developed in the future, these may be underestimates of the amount of future available water.

7.2 GROUNDWATER

7.2.1 Background

The availability of groundwater is a function of the physical characteristics of the aquifer at the location of interest (see Chapter 4) and the value of the intended use. For example, an industrial user may be able to afford to drill deep wells, sustain large drawdowns, and treat groundwater of undesirable quality, whereas an irrigation use may be economical only where wells are shallow, production is high, and quality is adequate without treatment. Virtually any of the "major" aquifers described in Chapter 4 could provide useful groundwater supplies, given sufficient development value. The "minor" and "marginal" aquifers could provide modest supplies of good-quality groundwater at many locations. Successful groundwater development in the "major aquicludes" group will be dependent upon locally favorable conditions and minimal quantity and quality demands.

Development of groundwater in sufficient quantities and of sufficient quality to meet specific project goals will require site-specific hydrogeologic analyses. None of the aquifers discussed in Chapter 4 are universally productive and none are entirely free of water quality concerns. While the generalizations of this report can provide guidance on the location and potential of various aquifers, local evaluation programs are essential to development success.

Table 7- 4 Future Average Annual Streamflow - Dry Hydrology and 50 Year Moderate Growth Scenario.

Surface Water Depletion Estimate in 2055 Moderate Growth Scenario	Acre-Feet/year
Municipal	11,596
City of Cheyenne	22,700
Industrial	123,700
Agricultural	399,480
Evaporation (In-state)	32,800
Recreation	NC
Environmental	17,000
Depletions Sub-Total	607,276
Full Development Main Stem Evaporation Charge	72,800

A.) Total Depletions	680,076
B.) Dry Scenario Total Streamflow from Table 4-1	1,452,316
C.) Flow Leaving Wyoming, 2055 Growth, Dry Scenario (B-A)	772,240
D.) Remaining Compact Amount, assuming 847,000 ac-ft allocation	166,924

Notes

Environmental Surface water depletions are those due to man made reservoirs used for environmental purposes.

NC = Non consumptive

2010 Basin Plan Estimate of Ag Surface Water Use is from Table 6-1. Derived by assuming equal to the irrigation consumptive use minus 7,800 ac feet for groundwater use in irrigation plus 1/2 projected stockwater uses. This assumes that Stock use is 50% surface and 50% groundwater.

2010 Basin Plan Estimate of Municipal Surface water use from Table 6-3

2010 Basin Plan Estimate of Cheyenne Surface water use from Table 6-5

2010 Basin Plan Estimate of Industrial surface water use from Table 6-10

2010 Basin Plan Estimate of Environmental Use from 2001 Plan, 30yr

Compact Allocation Estimate per SEO, October 1, 2010.

The State can store 120,000 ac-ft of water in Fontenelle Reservoir. The estimate of Remaining Compact Amount (Item D) is based on the assumption that the future industrial depletion shown will be met, at least in part, by the State of Wyoming Fontenelle Water Storage account.

The relationship between the groundwater and surface water portions of the overall water resource depends upon the location, depth, rate, volume, and use of the groundwater withdrawn, all in the context of the local and regional hydrogeologic environment. When a well is pumped, groundwater is removed from storage, creating a cone of depression. That cone will grow deeper and broader as pumping continues until a balance is established between pumping from the aquifer and inflow to the aquifer from 1) adjacent water-bearing rocks and/or 2) surface water sources. The latter may include stream infiltration induced by pumping, interception of groundwater flow that would otherwise continue towards discharge at the surface, or production of groundwater that would otherwise be taken up and transpired by plants (a capture process known as "ET salvage").

7.2.2 Diversion Rates

In general, groundwater diversion rates of less than 5 gallons per minute (gpm) are widely, although not universally, available throughout the Green River Basin. Diversion rates in the 5 to 50 gallons per minute (gpm) range are likely obtainable from most of the "major aquifers" shown on Figure 4-3. In the Green River Basin, 95.2 percent of groundwater wells have permitted yields of 25 gpm or less. Diversion rates in excess of 50 gpm may require favorable local conditions of permeability. Rates on the order of 1,000 gpm are only routinely available from certain areas of productive alluvium and from well-recharged and fractured areas of major bedrock limestone aquifers. There are 203 wells in the Green River Basin with yields from 100 to 3,600 gpm, and of these only 19 are in the 500-3,600 gpm range. Figure 7-6 presents data on groundwater wells in the Green River Basin. The above assessments are based upon instantaneous diversion rates that may or may not represent the conditions necessary to sustain those rates over extended periods when subject to the cumulative impacts of multiple wells or when stream depletion is an issue.

In addition to diversions, aquifer discharge of the main Tertiary Aquifer System in the Green River Basin is estimated to be 118,000 acre-feet/year, as shown in Table 7-5, and should be considered a constant diversion of groundwater.

7.2.3 Groundwater in Storage

A large quantity of groundwater is stored within the aquifers of the Green River Basin, although this quantity is very difficult to estimate accurately. The depth to the groundwater table is rarely more than a few hundred feet and beneath that water is stored in the pore space of the rocks to a depth where porosity falls effectively to zero, e.g., in the crystalline rocks known as "basement." Green River Basin Mesozoic sedimentary rocks—sandstone, shale, limestone, conglomerate—extend to depths of 30,000 feet. Thus there is a vast amount of groundwater in storage, although much of it is too expensive to develop as a useful resource due to unfavorable permeability, depth, or quality. Because

Figure 7-6 Types and Number of Permitted Wells in 2007

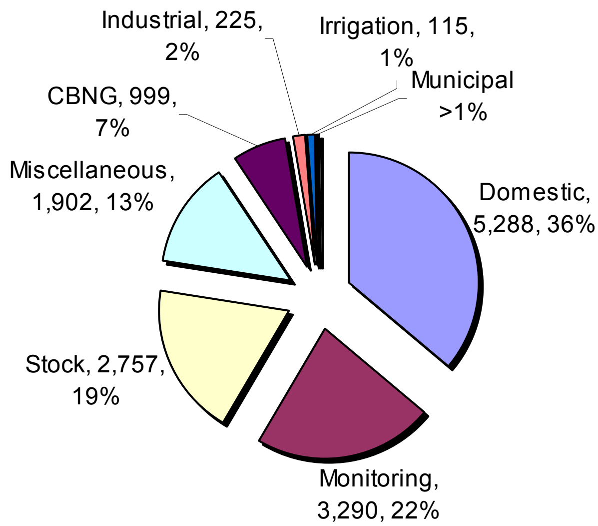


Table 7-5 - Estimated Discharge of the Tertiary Aquifer System

Discharge Component	Estimated Outflow Cubic-Feet/Second
Green and New Fork Rivers upstream from Fontenelle Reservoir	94
Green River between Fontenelle Reservoir & Green River, WY	23
Green River downstream from Green River, WY, including Flaming Gorge Reservoir	13
Big Sandy River	17
Henry's Fork River	16
Total	163
Total in Acre-Feet/Year	118,000

Source: Available Groundwater Determination, tech. memo, 2010 much of the groundwater is stored at these infeasible depths, calculations of groundwater in storage were conducted on the most heavily used and accessible Tertiary Aquifer system in the Green River Basin.

The Wyoming State Geological Survey (WSGS) carried out general calculations on rock and sand volumes in the top 1,000 feet of good quality water bearing portion of the Tertiary Aquifer in the Green River Basin to get a rough estimate of the amount of groundwater in storage. These calculations took into account estimated porosities of each substance, surface area covered by the aquifer, the vertical saturated thickness of the aquifer, and assumed the composition of the aquifer to be sandstone topped with unconsolidated sand. The total estimated quantity of groundwater contained in the Tertiary Aquifer system is approximately 1 to 2 billion acre-feet of water. However, this number does not represent the total quantity of groundwater that may be yielded to wells due to hydrostatic forces of water in the ground. Complete explanations of this estimate are contained in the *Available Groundwater Determination, tech. memo, 2010* referenced at the end of this chapter.

Groundwater in storage can be viewed as 1) a surface reservoir, from which water can be extracted repeatedly as it is subsequently refilled, or 2) a groundwater "mine", from which water can be extracted one time. The alluvial aquifer is most akin to a surface reservoir. It is filled either by stream flow infiltration or groundwater recharge that would otherwise proceed into the stream. Removal of stored water from an aquifer reduces stream flow, and that reduction continues until the reservoir is refilled. Where quantities of water in excess of contemporaneous stream flow are needed seasonally, the groundwater reservoir can be exercised to better align demands with supply by "evening out" surpluses and deficits. This process happens naturally across many of Wyoming's irrigated lands, as large springtime diversions generate return flows that sustain late-season stream flows.

While groundwater will ultimately be replaced from surface sources, that replacement may be so diffuse and over such a long time period that it is effectively a nonrenewable resource. In general, the deeper and more distant from surface water features the groundwater is, the smaller is the likelihood of a significant surface water connection.

The removal of groundwater from storage is indicated by a lowering of the groundwater table or in the case of a confined aquifer, by a decrease in pressure. Bedrock aquifers are generally deeper and more distant from streams than are alluvial aquifers and are more likely to experience groundwater level declines before production rates and recharge rates come into balance. Short-term fluctuations in groundwater levels may reflect seasonal variations in recharge and discharge, multi-season climate cycles, or deliberate drafting and recovery management. Long-term changes in groundwater levels indicate a deficit (or, in some cases, a surplus) of recharge relative to production. Where groundwater is closely connected with surface water, as in much of the alluvial aquifers, the locations and long-term availability of groundwater are effectively the same as surface water. Groundwater recharge is the source of "base flow" to streams. While matching groundwater consumption to recharge would prevent widespread groundwater level declines, it would also lead to dry streambeds for much of the year. Thus care must be exercised when extracting shallow groundwater resources in connection with surface water.

Except for some localized areas in the Green River Basin with a high density of existing wells, most of the remaining Basin area offers opportunities to develop additional groundwater resources. No areas have been identified in the Green River Basin with significant depletion (or “mining”) of the groundwater resources, which may require the establishment of a groundwater control area such as the groundwater control areas that currently exist within the Platte River Basin of southeast Wyoming. Two areas have recently started experiencing or are planning drawdown of water levels as a result of energy development. These two aquifers are the Tensleep Sandstone in the northeastern Great Divide Basin due to petroleum field development and the coal beds of the Mesaverde Group near Baggs due to the Atlantic Rim CBNG development. In addition, some degree of observed decline in the groundwater levels occurred across Wyoming, including the Green River Basin and adjacent areas, during the 8-year regional drought period from 1999-2007.

7.2.4 Groundwater Recharge

A common approach to estimating the quantity of groundwater available for continuous development, as opposed to one-time extraction, is to estimate groundwater recharge. Precipitation is the ultimate source for groundwater resources as part of the hydrologic cycle although man-made recharge may occur in local areas where human activities provide more water to the ground surface than occurs naturally. Examples of this include irrigation on cropland, reservoirs, irrigation canals and ditches, and industrial, stock, and wastewater ponds which all locally increase the infiltration quantity of water compared to the natural rate of precipitation.

It is generally assumed in hydrogeology that 10 percent of the amount of precipitation falling on the outcrops of bedrock formations infiltrates and recharges the aquifer. The average annual precipitation in the Green River Basin ranges from 6 to 59 inches per year with most of the Basin receiving 6 to 15 inches average annually. However, not all precipitation infiltrates into the ground to recharge the aquifer; a portion is consumed by evapotranspiration (the combined evaporation and transpiration losses of water in the vapor state to the atmosphere), overland flow, and runoff. Additionally, there are wet, average, and dry years with varying amounts of precipitation resulting in a range of possible recharge amounts depending on the hydrologic conditions of the year. Estimates of aquifer recharge rates range from less than one inch per year to twelve inches per year; generally the mountainous and highland areas experience greater recharge. Evapotranspiration rates in the Green River Basin are high because of the high altitude and arid climate. In the central basin areas the annual evapotranspiration rates exceed the annual precipitation rates to the effect that very little to no aquifer recharge occurs.

There is little consensus on a detailed estimation of groundwater recharge rates, which are a complex function of the seasonal timing, duration, intensity, and type of precipitation; the infiltration characteristics of the soil; the hydraulic properties of the uppermost geologic materials; and the manner in which groundwater recharge moves within and between aquifers. Previous estimates of groundwater recharge rates in the Tertiary Aquifer System of Green River Basin set the range of 50,000 to 100,000 acre-feet per year. Newer estimates in the *Available Groundwater Determination, tech. memo, 2010* approximate the number at about 119,000 acre-feet per year, as is shown in Table 7-6.

In summary, the above approach to estimating the amount of groundwater in storage and the total recharge to groundwater provide upper bounds on the possible supplies of mineable groundwater and sustainable groundwater production, respectively. As a practical matter, however, the available groundwater supply is substantially less.

7.2.5 Groundwater Quality

Most water uses have some sensitivity to water quality. Because of this, groundwater availability will be a function of how the quality from a particular aquifer and location aligns with the needs of a particular use. As explained in Chapter 4, natural groundwater quality is generally best closest to outcrop areas and deteriorates the longer groundwater has been in contact with aquifer minerals. This effect is weakest in the "major aquifers" and strongest in the "minor" and "marginal" aquifers.

Figure 4-5 shows an aquifer sensitivity map of the Green River Basin. These higher sensitivity areas are considered to be more susceptible to shallow groundwater contamination due to the increased permeability of these geologic units and also the relatively shallow depth to groundwater in these areas.

In some areas of the Green River Basin, groundwater contamination is natural and related to the elevated concentrations of chemical constituents from natural sources. Unnatural sources of pollution consist of mostly local incidences of spills and leaks. A more detailed commentary on groundwater quality is presented in Chapter 4.

7.2.6 Groundwater Summary

Groundwater availability is greatest for the Tertiary Aquifers in the Green River Basin, with the understanding that connections with surface water will have to be addressed. Table 7-7 shows SEO groundwater permits by type of use for the Green River Basin.

Table 7-6 - Estimated Recharge to the Tertiary Aquifer System

Recharge Component	Estimated Inflow Cubic-Feet/Second
Infiltration of precipitation, snowmelt runoff, and streamflow	138
Excess irrigation water in the Farson-Eden area	18
Streamflow leakage along the Blacks Fork, Smiths Fork, & Hams Fork Rivers	9
Total	165
Total in Acre-Feet/Year	119,000

Source: Available Groundwater Determination, tech. memo, 2010

Table 7-7 - 2007 Permitted Wells in the Green River Basin

Well Type	Number of Wells	Percentage of Total Wells
Domestic	5,288	36%
Monitoring	3,290	22%
Stock	2,757	19%
Miscellaneous	1,902	13%
Coalbed Methane (or CBNG)	999	7%
Industrial	225	2%
Irrigation	115	1%
Muncipal	55	>1%
Total	14,631	100%

Source: Available Groundwater Determination, tech. memo, 2010

7.3 WATER CONSERVATION

7.3.1 Introduction

In general, the Green River Basin has adequate water to serve the needs of its residents now and in the near future. For the most part water shortages are seasonal although their effects can be magnified by drought conditions. Water conservation is any beneficial reduction in water losses, waste, or use.

Sound long-range water conservation and planning measures and goals set forth by The Irrigation Association, an international organization founded in 1949, include:

- Measure all water use.
- Price water so as to recognize its finite nature, provide financial incentives to users who conserve water, and provide financial penalties to users who waste water.
- Hold all water users responsible for protecting the quality of the water that they use.
- Create financial systems to reward users of efficient irrigation systems.
- Create national education programs regarding the “absolute necessity of supporting regulatory policies which reward conservation and efficient water use”.
- Support water reclamation and reuse initiatives, particularly for irrigation, but also for municipal, industrial, and other water use sectors.
- Increase support for developing new water sources, including new conveyance and storage systems and incorporating into development plans appropriate environmental concerns.
- Maintain water conservation planning as an ongoing program.
- Promote policies which allow for the lease, sale, or transfer of “established water rights” and/or the lease, sale, and transfer of water without jeopardizing established water rights, whenever possible.

In recent years, dry conditions and record low storage levels in Lakes Mead and Powell have generated concern as to how to accomplish water curtailments when there is no plan in place to administer such a call which historically has never been necessary. The meaning of “curtailment” is complex and has specific definition under Article IV of the Upper Colorado River Basin Compact. It is beyond the scope of this document to explain the definition of curtailment and the reader is referred to the Compact document for the definition. Table 7-8 illustrates the impact of the recent drought period on the amount of water in Lakes Mead and Powell.

Table 7-8 - Upper Colorado River Basin Inflow and Principal Reservoir Storage

Water Year	Unregulated inflow into Lake Powell % of Average	Combined Lake Powell & Mead Storage in maf[1]	Lake Powell & Mead Storage as % of Capacity
1999	109	47.59	95%
2000	62	43.38	86%
2001	59	39.01	78%
2002	25	31.56	63%
2003	52	27.73	55%
2004	49	23.11	46%
2005	104	27.24	54%
2006	72	25.80	51%
2007	68	24.43	49%
2008	107	27.04	54%

[1]Million acre-feet.

Source: Wyoming State Engineer's Office. *2008 Annual Report*, 2008

Water conservation in Wyoming involves all uses including agriculture, municipal and domestic, industry, recreation, and environmental concerns. In the past, water conservation efforts were mainly focused on improving the efficiency of agricultural water use. Today, water conservation takes a multi-sector approach as conservation has different meanings at different times of the year and to different water users. The following is a discussion of water conservation activities and opportunities.

7.3.2 Agricultural Water Conservation

The largest water savings by quantity are generally realized by conservation in the agricultural sector, as it represents the largest use of water in the state. For this reason, much of the focus of water conservation is on irrigation practices.

Water is typically diverted from the river or stream into a canal or ditch, which is generally of earth construction and unlined. A significant portion of water diverted for irrigation can be lost during conveyance to the field through seepage, deep percolation, phreatophytes, evaporation, and so forth. The soils of the Green River Basin are predominantly porous; water will quickly percolate through these granular soils. Losses of 10 percent in irrigation ditches and canals are considered typical and normal; any ditches with a loss rate greater than 10 percent are candidates for rehabilitation. In the Green River Basin, there are a large number of ditches that exceed a 20 percent loss. Membrane liners have been used with good results on some of the large USBR canals around the state. Research has indicated that application of polyacrylamide (PAM) to the canal bottom and sides will reduce seepage losses and increase transmission efficiencies. Concrete, PVC incorporation, and fabrics are other more common and equally effective means of reducing seepage to surrounding soils. Where economics permit, replacing open ditches with pipelines can virtually eliminate conveyance losses.

Irrigation methods also present an opportunity for water conservation. Historically flood irrigation was the most popular method used and still is very popular despite its low efficiency. The use of gated pipe and surge valves has somewhat improved the efficiency of flood irrigation practices by reduction of runoff, seepage in laterals and deep percolation, but overall effectiveness remains low. Since the early 1970s many areas in Wyoming have converted to sprinkler irrigation, including hand lines, wheel lines, big guns, and center pivot systems. Sprinkler design and efficiency have also increased over time with the use of low energy consuming or low pressure application systems. Positive results from this transition to sprinkler irrigation include increased crop yields and allowing more acreage to be irrigated in the late season. Negative effects include less groundwater recharge and decreased enhanced late season streamflow due to reduced irrigation return flows.

Irrigation districts typically have very limited resources to expend on canal lining and covering efforts. A change in some areas to less water-intensive crops or, to a lesser extent, landscaping, would potentially reap savings in water consumption. Moving from flood irrigation to sprinkler methods, as well as enclosure and lining of open ditches and canals would further conserve water. Changing to less water-intensive crops and landscaping should most likely be held in reserve, since it has a high impact on accustomed ways of farming and life.

7.3.3 Municipal and Domestic Water Conservation

The Green River Basin municipal water suppliers are faced with several problems. They must provide sufficient water of good quality and plan for the demands of potential future growth. Some of the municipalities are experiencing additional growth through economic development efforts while others are dealing with impacts from energy exploration and development. The water suppliers also must comply with state and federal water quality standards, which are constantly revised and becoming more stringent; compliance is becoming more and more costly. Typically, the budgets for water system improvements, operation and maintenance are based on revenues from the sale of water; many municipalities must sell water to meet their financial obligations.

Conservation measures generally consist of individual customer meters that track actual water use, and can help determine if there are major losses in the distribution system through leaks. Many municipalities meter their public water systems, but some systems do not and have little or no incentive to conserve water. The expense of installing meters can be seen as prohibitive and is unpopular politically. Some systems are requiring meters on new hookups and considering phasing in metering for the existing population. Leak detection and repair in municipal systems, reclamation and recycling, and residential plumbing improvements are all proposed water conservation possibilities in the municipal and domestic domain of water use. Conversely, some systems encourage water use during the winter months to prevent frozen pipes.

Reclamation and recycling efforts have not so far been emphasized in the Basin given the high cost of water treatment systems and the ready availability of water. The use of partially treated wastewater for irrigation of golf courses and public green spaces has been implemented in some areas and could be considered on a case by case basis. A study for the town of Rawlins showed that the treatment plant output water was too brackish to be used for long-term irrigation without further treatment, and the towns in the Green River Basin would have a similar problem given the similar characteristics of the water and soils of the region to Rawlins.

Within the identified opportunities, small municipalities within the Basin may have difficulty with certain improvements from a cost/benefit perspective; however, all the conservation options are valuable from a publicity and educational standpoint. Particularly costly for the municipalities are the infrastructure repair efforts, for which bonds and financing can be a hard sell to the local populations unless water shortages are imminent.

7.3.4 Industrial Water Conservation

Industrial water use is important as industry employs a significant percent of the Basin's work force and constitutes a large portion of the Green River Basin's economy. Conservation by industry is constrained by cost-benefit ratios; the necessity of making a profit will outweigh water conservation measures. Thus conservation by industry differs by industrial sector.

Power plant modification can reduce consumptive use. The two large power plants in the Green River Basin, (Bridger and Naughton) both use an evaporative cooling mechanism with a combined annual consumptive use estimated in the Seven States Report at 33,230 acre-feet per year. The Seven States Report further suggests that most of this consumptive use could be eliminated if the plants were to retrofit to an air-cooled system. The costs of such a modification ($1,000 to $4,000 per acre-foot recovered) do not look promising at the present time, and there are cost penalties in the form of lower plant efficiency, but the opportunity certainly does exist.

Desalinization of brackish water, especially Wyoming CBNG production water, could augment the usability of waste water. At present, most CBNG water in the Basin is injected into deeper aquifers to avoid disposal and treatment costs and problems since the water is generally brackish. Assuming the cost of desalinization would be similar to that reported by the desalinization project in Yuma, Arizona, a base cost of about $700 to $2,000 per acre-foot would be expected, depending largely on the cost of electricity. In addition, there are water conveyance and collection problems because the CBNG wells are dispersed throughout the Basin. Currently, some ideas for this option are under study, but any solution based on this option would likely be applied first in the Powder River Basin.

7.3.5 Recreational and Environmental Water Conservation

Three federal programs, the Conservation Reserve Program (CRP), the Wetlands Reserve Program (WRP), and the Wildlife Habitat Incentives Program (WHIP) encourage the development of wildlife habitat on private lands. The CRP is administered by the Farm Service Agency of the U.S. Department of Agriculture (USDA) and provides incentive payments for various conservation practices that will enhance wildlife habitat, as well as improve water quality and reduce erosion. The WRP is administered by the Natural Resources Conservation Service (NRCS) of the USDA. It is a voluntary program that provides financial and technical assistance to private landowners to reestablish wetlands on their property. The WHIP is also administered by the NRCS, and it provides technical and financial assistance to private landowners interested in improving wildlife habitat on their property. None of these programs result in significant amounts of consumptive water use. More lands in the Basin are expected to be enrolled in the CRP in the future, although no acreage estimates were made for purposes of this water plan. Most CRP lands do not involve consumptive use of surface water and thus will not affect future surface water availability for other uses.

Funding for non-consumptive uses such as environmental and recreational uses is a concern. There also exists the notion that environmental and recreational needs are not always compatible with storage. Where instream flows are desirable, the hydrology of the natural stream system still cannot put water into the river in a dry year unless those flows are tied to storage. Compounding the conflict, where run-of-the-river hydrology is favorable for aquatic and riparian habitats (and recreation pursuits), the reservation of flows for this purpose, while valuable, may preclude the use of this water for other consumptive needs allowed under the governing compacts. In fact, Wyoming's Instream Flow Law requires that instream flow use "shall not result in more water leaving the state than the amount of water that is allocated by interstate compact or United States Supreme Court Decree for downstream uses outside of Wyoming."

7.3.6 Conclusion

In order for conservation methods to be successfully implemented, there must be an incentive or benefit for those involved. This incentive may be in various forms, such as increased crop yields, improved fishing, reduced costs, and so forth.

Reduction of conveyance losses and improvement of irrigation efficiency do not necessarily equate to less water used. In areas of deficit, conservation measures may result in the conserved water being applied to additional acres or providing a full supply of water throughout the season without a decrease in the water diverted. However, these improvements in efficiency will likely result in an increase in the crop quality and yield.

Under the prior appropriation doctrine, water left in the stream is available to other users. An appropriator can invest in conservation measures that result in the water savings remaining in the stream, however, there is presently no mechanism whereby the appropriator can capitalize on those savings and realize an economic gain for his investment. As a result there is little incentive to invest in conservation measures that leave water in the stream for use by others.

The Green River Basin has surplus water when viewed from a basinwide perspective. Because there is excess water supply, local motivation to support intensive or even modest investments of time and money on water conservation is not strong. The state should promote conservation as a best practice policy, consider changing water law to reward conservation efforts to the appropriate stakeholders, support all local efforts and initiatives toward water conservation, particularly as irrigation districts consider conveyance improvements which may be beyond their means but of benefit to the Basin as a whole, and continue to monitor the conservation studies and efforts of others, particularly the Lower Colorado Basin work. Since the Green River Basin's situation is unique and dynamic, the opportunities and economies for conservation may differ from those found in other locations, but water users in the Basin should continue to evaluate and develop conservation as one important piece of the water resource puzzle.

7.4 REFERENCES

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8.0 STRATEGIES AND RECOMMENDATIONS

8.1 INTRODUCTION

The previous chapters of this plan characterized the nature, distribution, and current uses of the Green River Basin's water resources and provided estimates of future water needs. Compiling this information was the primary purpose of the 2010 Green River Basin Plan.

The secondary purpose of this project was to perform planning. The Basin's water users face challenges concerning present and future water uses, and these challenges go beyond the need for locating and beneficially using more water. Users are faced with challenges related to water quality, infrastructure maintenance, water supply reliability, climate variation, project funding, energy costs to move water, and many others. In addition, the span of water issues and challenges is broad, from relatively small specific problems affecting a particular community or irrigation district to widespread issues potentially impacting users within and outside of the Basin.

8.2 PLANNING OBJECTIVE

The objective of this chapter is to present a useful continuation of the 2001 Green River Basin Plan's planning process. During and immediately after preparation of that plan, a great deal of work was done to identify and discuss water issues and challenges. While issues and challenges do not remain static and deserve a continuous discussion, at some point effective planning must advance beyond issues discussion towards a solutions discussion. Therefore, a clear objective of this 2010 Green River Basin Plan Update is to advance the planning process beyond issues identification and into a useful identification of strategies and recommendations for addressing issues.

The following definitions are used for this planning process to help explain the important difference between strategies and recommendations:

- **Strategies:** broad and general activities that stakeholders may employ to address what is typically a host of issues. As an example: A Municipal Master Plan is a strategy that a community can use to address the multitude of issues typically facing this particular user group. This can include economic development, water supply and distribution, wastewater treatment, infrastructure funding and financing, etc.

- **Recommendations:** specific activities that individual stakeholders may implement to address specific and well defined strategies.

8.3 ISSUE SUMMARY

The 2001 Green River Basin Planning process initiated an identification and discussion of water issues and challenges in the Basin. Through a series of public meetings, the many challenges facing water users were identified and recorded. The Basin issues list was refined and consolidated by Water Development Office (WDO) staff and completed in November 2005. Table 8-1 presents the issues list.

Agricultural Issues

Agriculture is the major water consumer in the Green River Basin. In some areas and in some years irrigators in the Basin experience large seasonal shortages. The major reservoirs in the Basin, Fontenelle and Flaming Gorge Reservoirs, are downstream of most of the Green River Basin irrigated areas and are virtually unused for irrigation in Wyoming.

The distribution of water storage is uneven, so that some irrigated areas are well served by one or more reservoirs while others have little or no storage. The Upper Green River except for the New Fork River has little storage; in this area there are a total of 119,302 irrigated acres but only 6,495 acre-feet of storage. This provides a ratio of 0.05 acre-foot of storage per acre of irrigated land, and the irrigated lands in this area typically do not receive a full water supply in most years. Another reach with water supply problems is the Henrys Fork, which has a storage ratio of about 0.41 acre-foot of storage per acre of irrigated land. The Hams Fork is another portion of the Basin without irrigation water storage.

Besides inadequate storage, agriculture faces infrastructure deficiencies. There is a lack of water measurement devices to aid in water management, canals leak, and many diversion and headgate structures are old and in need of repair.

Municipal and Domestic Issues

Municipal systems are challenged to meet water quality treatment requirements and to produce and distribute adequate supplies, especially during drought conditions. Some municipalities need more storage, replacements for aging infrastructure, or to extend their networks into new service areas. The water sources (ground and surface water) are also threatened by contamination from water users, unregulated rural septic systems, failing infrastructure, and natural sources. The presence of senior water rights poses a threat to some municipalities, such as Baggs and Bairoil, if informal agreements with industrial and agricultural sectors are not honored or if growth in municipal water demand is large.

Table 8-1 Issues Identified in the Green River Basin

Issues Identified	Sub-Issue	Current Status[1]
		- Church Reservoir Study
		- Upper Green Study
		- BLM Stock Reservoirs (small water projects)
		- Viva Naughton Level II Phase I and II Studies
		- Middle Piney Reservoir New Project Application
		- Eden Valley Pipeline Level III Project
		- Boulder Reservoir Level II
		- Weather Modification Study
		- Water Value Study
		- Green River Groundwater Recharge and Alternate Storage Study
		- High Savery Reservoir
Agriculture	Additional Storage	- Salinity Control Project
		- Green River Groundwater Recharge and Alternate Storage Study
		- WWDC Small Water Projects
		~Sweetwater Conservation District - 14 wells and 1 pipeline
		~Little Snake River Conservation District - 8 spring developments and 2 solar platforms
Groundwater		- Wamsutter Well
		- Water Value Study
Economic Development		- Upper Green Joint Powers Water Board
		- Colorado River Compact Administration Report (Mike Purcell)
		~3 public meetings
	Instate	- SEO budget request for Colorado River Coordinator position
		- Upper Colorado River Compact Commission
		- 7 States discussion
		~California quantification
		~Lake Powell/Lake Mead storage equity
		~Additional supply needs for City of Las Vegas
Downstream Claims, Compacts and Decrees	Downstream	- Quantification of supply under compact
		- Big Sandy pipeline
		- WWDC Small Water Projects
		~ Sweetwater Conservation District - 14 wells and 1 pipeline
		~ Little Snake River Conservation District - 8 spring developments and 2 solar platforms
		- SEO Atlantic Rim Water Management Study (2006 Legislation)
	Instate	- 205 (j) Projects
		- Salinity Control Forum
		- Ft. Bridger area salinity review
		- 303 (d) (DEQ)
		- Fremont Lake Monitoring (municipal supply for Pinedale) in conjunction with Lakeside Lodge Expansion EA
Water Quality	Basinwide	- Coalbed Natural Gas Development
		- Baggs
		- Wamsutter
		- Bridger Valley
		- Green River/Rock Springs Master Plan
Municipal and Domestic		- Metering requirements
		- Green River Supply Canal Level II and Level III Projects
		- Little Snake System
		- Eden/Farson (Big Sandy Salinity Control Project)
		- Eden/Farson pipeline
		- Green River/Rock Springs water reuse on parks and golf courses
		- Municipal metering requirements
Water Conservation and Reuse		- Coalbed natural gas development (water discharge, storage, reinjection)
		- Pinedale desire for instream flow through town
		- Water Plan listing of instream flow applications
		- High Savery Reservoir fish pool
		- Maintaining overall watershed/environmental health (wetlands)
Non-consumptive and Aesthetic Uses		- Coalbed Natural Gas Development
		- (revisit entire list)
		- Fontenelle Water Sales
		- Quantification of remaining compact allocation
Water Development		- BORs management of water in Fontenelle Reservoir
		- High Savery Reservoir fish pool for Colorado River cutthroat trout
		- Endangered Fish Recovery Program
		- Yampa Programmatic Environmental Impact Statement (EIS)
		- Energy Development (leasing of federal lands and mineral rights)
		- Marketing of water out of Fontenelle (Bureau of Reclamation)
Federal Involvement, Regulations, and Lawsuits		- Coalbed Natural Gas Development
		- Green River Water Park
		- Storage
		~Flaming Gorge Reservoir
		~Viva Naughton Reservoir
		~ Fontenelle Reservoir
		~ High Savery Reservoir
		~BLM Stock Reservoirs (Old Steve Adams #5)
		- Purchase of agriculture lands for "non-traditional" uses
Recreation		- Other recreational uses on reservoirs and streams in the Basin (fishing, floating, bird watching, etc)
		- Trona
		- Jim Bridger Power Plant
		~Kemmerer need for reliable water supply
		- Coalbed Natural Gas, Oil and Gas Development (Jonah)
		- Oil Shale Development
		- Simplot Phosphates
		- Synthetic-based fuel from coal (coal liquification)
		- Enlargement of Jim Bridger Power Plant (possible enlargement of Viva Naughton Reservoir and others)
		- Governor's proposed energy corridor (water needs)
Industry, Minerals, and Manufacturing		- Reinjection of produced water below 7500' (Pinedale Anticline and Jonah Field)
		- Dry year leasing
		- Temporary water right transfers
		- Drought updates from State Climatologist
		- Winter snowpack augmentation
Drought Mitigation and Flood Control		- Bureau of Reclamation operation plans
		- Pinedale: instream flow through town
		- Transbasin diversions
		- Subdivision administration
		- SEO: increased penalty to those taking water without a permit
		- Ongoing Compact Work
		- Mapping project (SEO) and consumptive use analysis (Colorado River Compact Administration Project)
Water Rights		- Increased measuring devices and accuracy in diversions
		- Upper Green River Joint Powers Board
		- Water Value Study
Implementation		- Groundwater in Water Plan updates

1. Issues list current as of November 2005.

Industrial Issues

Industrial users have adequate supplies to meet existing uses. In general, the supplies are reliable due to their location in the Basin and the presence of water storage facilities and long-term supply contracts. Future industrial users will be challenged, depending on project-specific requirements and location in the Basin. Industrial water issues include water quality treatment and disposal regulations. In the Basin, compact salinity requirements place additional constraints on already stringent EPA and WDEQ regulations with the goal of meeting the Colorado River Salinity Control Act requirements by eliminating additional salt loads. A major obstacle to CBNG development was the question of alternatives for disposal of byproduct saline groundwater considering the expense of injecting the water into brackish formations. Aging transmission systems, outdated technology and equipment, and the cost-benefit ratios that constrain updating are all issues in this sector.

Recreational and Environmental Issues

Environmental water uses are non-consumptive, but important to the Basin. As an example, instream flows promote more favorable late season water temperature (i.e. lower), dilute pollution, and help maintain habitat quality for sport fisheries. While stream barriers, such as diversion dams, are a necessary and long-standing part of legitimate water use, fish bypasses and fish-friendly headgate/diversion structures can provide important benefits to fish and other species. Non-native species infestation, water quality impairments such as sediment, nutrients, salt loading, and other pollution all threaten environmental uses.

Recreational water use can conflict with the consumptive water uses of the other sectors. Water diverted for irrigation reduces flow rates in a particular reach of stream. During late summer, particularly in dry years, legitimate and longstanding uses can temporarily eliminate some recreational uses such as floating. Projects to develop water for new or supplemental uses can be designed to furnish multiple use benefits. Some specific recreational water use issues in the Basin include maintaining minimum pools, bacteria levels in recreational waters, and general aesthetic benefits of having adequate water or flow levels in streams, lakes, and reservoirs.

Basinwide Issues

Recently the Colorado River Basin suffered the worst drought in a century and one of the most severe in 500 years. Recent research from tree ring studies and hydrologic data have shown that the Colorado River is drier and more prone to severe drought than previously believed. It has also become apparent that the period of record of hydrologic conditions that was available and on which the Colorado River and Upper Colorado River Basin Compacts were negotiated were wetter than the long-term norm. Although to date there has never been a compact call on Upper Colorado River Basin states due to shortages, scientific evidence points to the likely probability that the compacts were signed under assumptions of wetter hydrologic conditions than can be expected over the long term. This affects Wyoming's compact allocation, because the Upper Basin states must still comply with the depletion requirements of the Compact, as presented in Chapter 3. The potential for drier conditions and sustained drought in the future establishes a need for the Basin to have an operating procedure in place to meet future compact calls.

8.4 APPROACHES TO STRATEGY IDENTIFICATION

As previously discussed, the issues identification process began in the previous basin plan and a goal of the current plan is to shift planning focus from issues towards strategies. The Planning Team performed the following activities to support the strategy-related planning recommendations presented in this chapter:

Basin Advisory Group (BAG) Meetings

Facilitated BAG meetings held around the Green River Basin included presentations from a variety of BAG members. The presentations were an opportunity for the Basin residents to describe their challenges and the strategies that they were evaluating or using to meet the challenges. The presentations were followed by open audience discussions brainstorming ideas for how the stakeholders could address the issues. BAG meeting notes provide a record of the information and suggestions collected at these meetings. These notes are compiled in the Plan Project Notebook, a single copy of which is possessed by the WDO.

Stakeholder Interviews

A phone survey, performed by WWC Engineering staff in late 2008, was directed at approximately 115 Basin stakeholders (55% response rate), including municipalities, industrial water users, agricultural interests, recreational interests, and a number of local, state and federal agencies. The survey had two objectives. First, the survey was used to identify water use issues currently affecting individual stakeholder groups. The 2008 issues survey was used to supplement and build on the extensive issues identification work performed as part of the 2001 Plan. The 2008 phone survey provided an opportunity for individual stakeholders to voice their personal opinions and ideas.

The second goal of the phone survey was to inquire about possible solutions (strategies) to issues that are affecting water users. While strategies for addressing issues are generally intuitive and in many cases widely known and discussed, the current water plan update was designed to directly ask the user groups themselves for strategy ideas. It was expected that water users would have different perspectives on possible strategies than the Planning Team and the WDO wanted to employ a grass-roots approach to preparation of the 2001 Basin Plan.

Planning Team Input

During the course of completing the various technical efforts, such as the water availability quantification in Chapter 7 and the technical memoranda regarding water related topics (e.g. Augmentation, Climate, etc), the Planning Team Members (consultants, state agency staff, and state agency directors) cooperated, discussed and evaluated strategies and considered specific recommendations. Many of the ideas generated in this way are expressed in a later section of this chapter.

8.5 GENERAL STRATEGIES

This section presents a general discussion on strategies. The strategies offer benefits to each water use sector in the Green River Basin, some more directly than others. Many of the concepts are not new; some were previously presented in the Wyoming Framework Water Plan. Wherever possible, the strategy concepts have been tailored to specific issues in the Green River Basin. These concepts supplement the more specific recommendations presented later and are described below in an order that does not indicate any particular priority.

8.5.1 Continue to Support Planning

The foundation of sound water planning strategies is the collection of information through planning studies and reports. Information collected in planning studies and reports, such as municipal master plans and watershed plans, are a major funding and improvement tool for municipalities and conservation districts, irrigation districts, and virtually any other non-municipal stakeholder in the Basin. The WWDC New Development Program and Rehabilitation Program provide opportunities for municipalities and other stakeholders to sponsor Level I and II studies, including municipal master plans and watershed plans (also see Chapter 9). These state-funded planning tools make possible the identification of problems and provide funding sources to help correct those problems. State-provided planning funds make it feasible for municipalities and stakeholders with limited financial resources to develop plans to solve critical water-related problems. The WWDC's Small Water Project Grant Program, Groundwater Development Grants, and New Development and Rehabilitation Programs provide entities with the means to begin addressing specific municipal, agricultural, and domestic water issues.

The water planning process documents the Green River Basin's intent to develop the means to use the allocations that have been made to the Basin through interstate compacts.

8.5.2 Consider Transbasin Diversions

The movement of water from areas of surplus to areas of need is woven through the water development history of the West, including Wyoming. It can create conflicts between water users in adjacent river basins, but it can also be a positive solution for the basin needing the water while addressing other needs in the basin of surplus via mitigation. Transbasin movement of water is expensive (thus precluding its use for irrigation), time-consuming (due to the number and complexity of environmental and other regulations that require permits, NEPA documents, etc.), and fraught with political and social debates. Before any transbasin diversion out of the Green River Basin is considered, there should be an evaluation showing that the basin receiving water has effectively developed and is using all reasonably available supplies. Also, in the event a transbasin diversion project is pursued, any resulting impacts to the basin providing the water must be mitigated according to Wyoming statute (W.S.41-2-121). Because the Green River Basin has unused compact allocations and is therefore the Basin most likely to be the source for water in any transbasin diversion, the requirement for mitigation could be an opportunity to barter surplus water for in-basin improvement projects such as reservoir construction or enlargement and infrastructure improvements to agricultural and municipal sectors. High Savery Reservoir is an example of mitigation constructed in exchange for an out-of-basin diversion by the City of Cheyenne.

The Million Conservation Resource Group (MCRG) has proposed the Regional Watershed Supply Project. The project would divert as much as 250,000 acre-feet of water per year from the Green River in Wyoming, possibly at Flaming Gorge Reservoir and pump the water through a pipeline along the I-80 corridor to Laramie, providing 25,000 acre-feet per year to water users in the Platte River Basin in Wyoming and transporting the remaining 225,000 acre-feet per year to the Front Range in Colorado. An Environmental Impact Statement (EIS) is being financed by the MCRG and prepared by the U.S. Army Corps of Engineers (USACE). It is anticipated that it will take more than five years to complete the EIS. The Bureau of Reclamation, as the federal agency in charge of Flaming Gorge Reservoir, is completing a study to determine the amount of water that may be available to the project.

In addition, a coalition of public entities in Colorado and Wyoming are pursuing a similar project as the Colorado/Wyoming Water Supply Project. The physical project is essentially the same concept, however, public financing is being sought by the coalition. This coalition is presently seeking members among public entities in Colorado and Wyoming.

The State of Colorado has not taken a position on either trans-basin diversion proposal. The State of Colorado’s support is critical to the proposals as the water to be delivered to Colorado must come from that state’s compact allocation under the Upper Colorado River Compact. The compact allows one state to divert its compact allocation in another state.

The transbasin diversion proposals are being monitored and scrutinized in Wyoming for potential environmental and economic impacts. On July 27, 2009, Governor Dave Freudenthal provided scoping comments on the EIS to the USACE. While the comments were comprehensive and expressed several concerns about the proposal, the Governor was particularly emphatic on the following issue:

> *“Wyoming recognizes Colorado’s right to develop its compact allocation pursuant to the Upper Colorado River Basin Compact, and that development in one state for use in another is allowed...* ***However, and I mean to add emphasis by employing bold font, the Colorado uses served by this project cannot affect, in any way, or deny any future uses in Wyoming, which of course will have later priority dates.*** *As such the NEPA analysis must consider that diversions for use in Colorado will be conditioned by Wyoming such that they will always be the most junior users of the lower river above Flaming Gorge.”*

The project has many hurdles to overcome if it is to become a reality, including, but not necessarily limited to, difficult environmental permitting and political issues; an estimated construction cost in excess of 3 billion dollars; and very extensive annual operating costs.

8.5.3 Evaluate Water Rights Leasing

The vast majority of early-priority water rights in Wyoming are direct flow surface water rights for irrigation. The property right that is conferred with an adjudicated water right makes these early water rights very valuable. As the state's economy diversifies, the municipalities and industries that require a consistent, dependable water supply might look to these senior agricultural water rights for transfer, as has happened in other parts of the state. While permanent changes of use are allowed under existing water law, and qualifying temporary changes of use are allowed for up to two years, more flexibility in the ability to transfer water rights on a temporary basis may be sought by water users. Concepts such as rotational land fallowing and dry year leasing have been used in other states to keep agricultural water rights tied to the land but give the water right holder the flexibility to make contractual arrangements with others in need of a dependable water supply during times of drought. These arrangements keep land in a higher category of agricultural land use (i.e., irrigated vs. dry land), which is good for local economies since property taxes are based on land valuation. It also provides water to those entities in need of water only in the years when their other water supplies are insufficient without permanently severing the water rights from the land. Some relatively minor changes in water right law could allow for more flexibility and better adaptation to the changing demands on water today.

8.5.4 Evaluate Changes to the Instream Flow Law

Modifying the Instream Flow Law enacted in 1986 could prove beneficial to the Green River Basin. The law does not currently allow for a private water right holder to retain his/her water right and change the existing use to instream flow, but requires that the right be turned over to the WWDC if the use is instream flow. Some landowners are interested in the fishery and environmental attributes of surface water resources on their properties. The ability to have more flexibility in the use of their surface water rights appears to be desired, and it is possible that changes to the instream flow statute and temporary change statutes could occur to accommodate the needs. Since 2002, at least twelve bills addressing the concepts of temporary in-channel uses or other flexibilities in the temporary use law have been introduced in the Wyoming Legislature, but none have passed. The Green River Basin planning process has identified that there is some support (Trout Unlimited, WG&F, and some landowners, as examples) for reserving water for instream purposes. Future BAG meetings can provide a forum for the public to provide input on whether increased flexibility is desired by water right holders for these uses of water.

8.5.5 Prepare for Climate Variation

Climate extremes contribute to seasonal and annual fluctuations in water supply and, to a lesser degree, changes in water quality. Impacts of climate change on water supplies are difficult to predict, but if the 1998-2007 trend of reduced snowpack, earlier snowmelt, and lower runoff amounts continues, stakeholders in the Green River Basin will have to adapt. Adaptation, supported by planning and preparation, will lessen the impacts. Below are specific ways the different water use sectors can prepare for climatic variation.

- Irrigators may want to ensure that their most senior water rights are on their most productive lands. This would assist in achieving the maximum benefits from a limited water supply. Moving the senior water rights will require approval of the Wyoming Board of Control, and there are some costs associated with the preparation of the necessary petitions.

- It is incumbent on municipalities and purveyors of domestic water to ensure that their citizens have enough water for the public's health and safety. Some Green River Basin communities have programs that place restrictions on the watering of lawns and gardens during periods of limited supplies. These restrictions help reduce the demand on available supplies. However, municipalities relying solely on direct flow diversions gain little from such water restrictions. These communities need to pursue supplemental storage or obtain water from senior water rights through temporary use agreements in times of drought when their direct flow water rights may be subject to regulation.

- During extreme, short-term drought events, industries may consider temporary use agreements with water users having very senior water rights.

8.5.6 Continue to Evaluate Storage

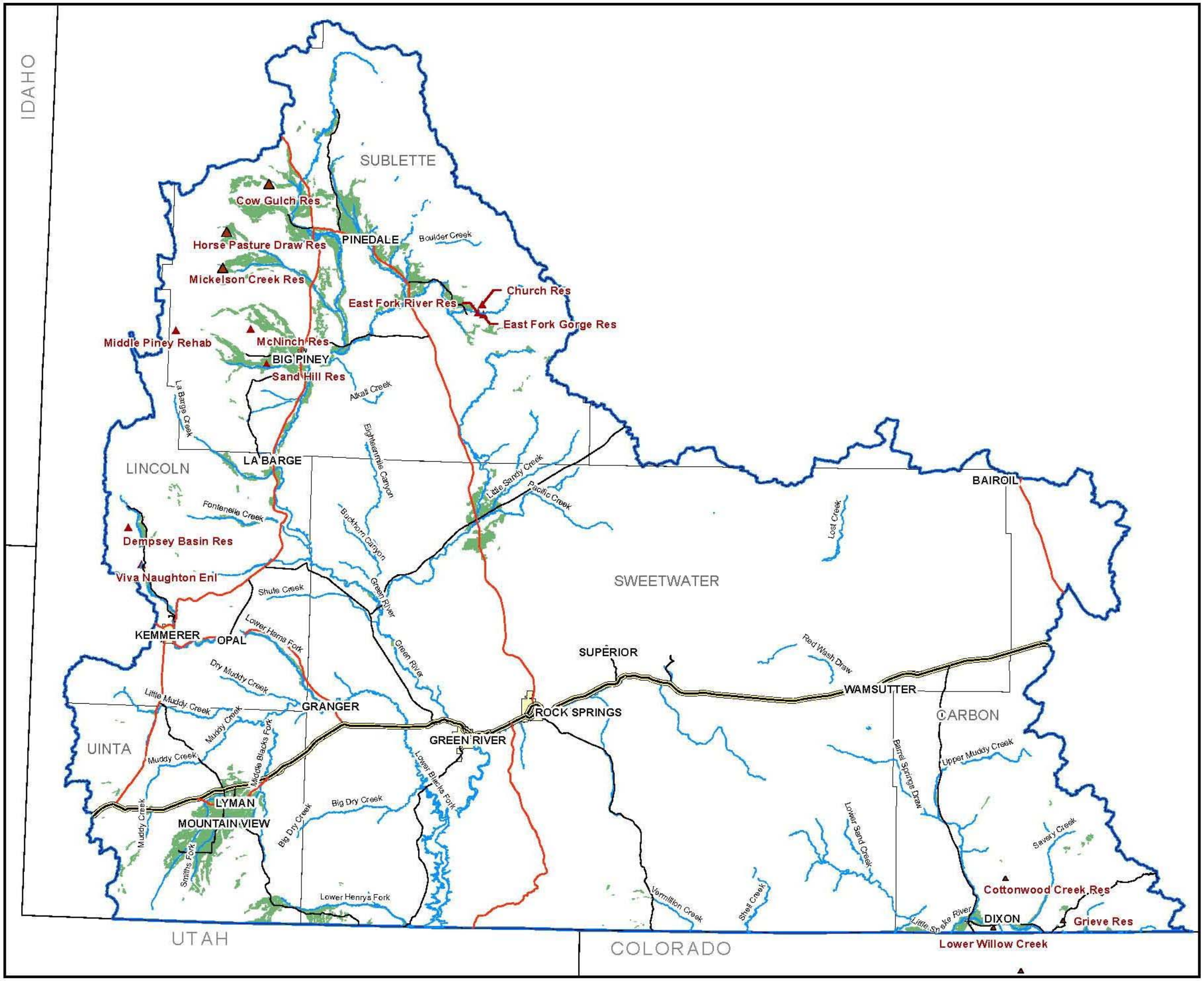
One water-shortage strategy that has always received considerable attention is the construction and enlargement of reservoirs. Although storage is generally a more expensive option than change of use from irrigation to municipal or industrial use, and may face environmental, cultural, technical, and legal obstacles, it is often preferred because it is a way to capture and store water for Wyoming and the Green River Basin's use without sacrificing another beneficial use. Storage helps to secure future supplies, may help to meet compact calls with the least impact to individual stakeholders, and generally enjoys widespread public support, especially when accompanied by environmental provisions such as minimum pools, minimum releases during low-flow periods, and fish bypasses. However, it is necessary for a sponsor of a reservoir construction project to demonstrate a need for the storage, including identification of alternatives considered and specific uses once completed. Water placed in storage must have a specific use, and until currently un-leased water in Fontenelle and Flaming Gorge Reservoirs is leased, it will be hard to demonstrate a specific need for additional storage in the Basin aside from areas which cannot be served by these two reservoirs. Table 8-2 and Figure 8-1 show a general list and location of potential reservoir sites and potential reservoir enlargement projects that have been identified by previous planning studies in the Green River Basin.

In addition, the Wyoming Water Development Program (Program) should remain committed to the construction of reservoirs (also see Chapter 9). Increased environmental regulations have made the construction of large dams on main stem rivers very costly and, absent

Table 8-2 Potential Reservoir Rehabilitation or New Construction Sites

Project	Storage	Irrigated Lands	Project Yield	2007 Project Cost	Storage Cost	Sponsor Cost per Acre*	Sponsor Cost per Acre-Foot*	Comments
	ac-ft	acres	ac-ft per year	$M	$ per ac-ft	$	$	
Middle Piney Rehab	4,200	NA	NA	NA	NA	NA	NA	Piney Creek drainage.
Horse Pasture Draw Res	5,710	15,151	5,152	20.6	3,608	33	98	North Horse Creek drainage off-channel site.
Sand Hill Res	14,500	10,000	14,100	32.8	2,262	80	57	Piney Creek drainage off-channel site would require 3-mile canal.
Church Res	10,000	5,497	4,200	20.5	2,050	91	120	East Fork drainage off-channel site would require 2-mile canal; water supply concerns.
Dempsey Basin Res	24,000	10,287	10,700	NA	NA	NA	NA	Off-channel site; Hams Fork drainage; critical cultural impacts.
Grieve Reservoir Rehabilitation	400	NA	300	0.5	1,250	NA	41	Little Snake drainage, off-channel.
Viva Naughton Enl	24,000	10,287	10,700	NA	NA	NA	NA	Hams Fork drainage; critical cultural impacts; large wetland impacts; multipurpose reservoir.
Mickelson Creek Res	7,300	19,183	5,835	31.9	4,370	41	133	South Cottonwood Creek drainage off-channel site.
Cow Gulch Res	13,330	11,583	2,793	19.5	1,463	41	170	Beaver Creek drainage off-channel site.
McNinch Res	4,600	6,000	5,600	28.6	6,217	117	125	Piney Creek drainage off-channel site would require 6-mile canal.
Lower Willow Creek Res	23,190	10,011	5,943	45.1	1,945	110	185	Willow Creek drainage.
East Fork Gorge Res	1,900	5,497	1,900	30.7	16,158	137	395	New Fork drainage.
East Fork River Res	1,700	5,497	1,700	19.1	11,235	85	275	New Fork drainage.
Upper Willow Creek	10,000	NA	4,570	22.5	2,250	NA	121	Little Snake drainage located in Colorado.
Upper Cottonwood Creek	1,000	NA	NA	7.2	7,200	NA	NA	Little Snake drainage.

* Assumed WWDC Standard Funding Package of two-thirds grant and one-third loan at four percent interest rate.



LEGEND

Irrigated Lands

Future Water Use Opportunity Sites

Figure 8-1
Green River Basin
Potential Reservoir Sites

federal reform to these requirements, virtually infeasible. Therefore, the Program should concentrate on smaller reservoirs on tributaries or off-channel reservoirs where environmental consequences can be effectively mitigated and managed. In addition, enlargements of existing reservoirs should be considered. Reservoir projects are more feasible if the Program works with project sponsors who are willing to commit political and financial capital towards the construction, operation, and maintenance of the project. In these situations, the Program should fund the permitting and design costs and provide construction funding commensurate with any water supply benefits it may retain for environmental purposes or future marketing. The sponsor should be able to finance a portion of the construction costs through a loan from the Program. The amount of the loan would be based on ability to pay for the benefits that the sponsor will realize in keeping with current practices of the Program. The sponsor should be responsible for operation and maintenance of the dam and appurtenances. In addition, developing partnerships with industries to construct new storage should be pursued. The Program's role in such partnerships would be to assist in the permitting of the project and invest in a portion of the storage for purposes of supplemental municipal and irrigation supplies. Also, much of the permitted capacity in existing reservoirs is eroding due to the accumulation of sediment. Given the value of storage to the state and the fact that many dams fill only in wet years, perhaps the state's one-fill rule should be revised to allow dam owners to ensure that the total permitted capacity is either used or stored.

8.5.7 Consider Water Conservation

Water conservation, both municipal and agricultural, is often touted as an approach to stretching water supplies. Conservation of water cannot be forced, however, and creating financial or other incentives to encourage reduced water consumption is typically required. Water conservation activities can also be complementary in addressing concerns with aging infrastructure. Over a hundred years of use has taken its toll; physical wear and time have deteriorated many of Wyoming's major water storage and delivery projects, leading to reduced water delivery efficiencies. Further, as competition for limited federal dollars increases, funding to replace or repair these projects will likely come from a combination of sources, not just the federal government. Future water plans should address the physical condition and continued functionality of aging water projects in the Basin and estimate the rehabilitation needs and costs. With this information, funding packages can be investigated, whether the funding is from federal, state, or private sources.

8.5.8 Consider Water Augmentation

The states of the Colorado River Basin are jointly exploring the feasibility of augmenting supplies through such means as weather modification, water conservation, water reuse, and desalination. It is difficult to distinguish between water that is a direct result of augmentation (e.g., cloud seeding) and naturally-occuring water. Therefore, augmentation is a strategy for the state to consider.

8.6 RECOMMENDATIONS

This section presents specific strategy recommendations for water development in the Green River Basin. For clarity:

- The recommendations are organized by the use sector categories.
- The recommendations are brief. Many of these recommendations have been previously published (in technical memoranda and other reports) along with well developed arguments to support the recommendations.
- The section includes suggested action items that were extracted from the BAG meeting notes, and some of the concepts are not fully developed or feasibility has not been determined.

8.6.1 Agriculture

Watershed Plans

Based on the distribution of agricultural interests and population, the following is a suggested prioritization of the order in which watershed plans should be initiated in the Green River Basin:

	HUC-8 (4th Level)
1) Upper Green	(14040101)

It is suggested that the west side of the watershed have a higher planning priority than the east side.

2) Blacks Fork	(14040107)
3) New Fork	(14040102)
4) Big Sandy	(14040104)
5) Upper Green Flaming Gorge	(14040106)
6) Little Snake	(14050003)
7) Muddy (west)	(14040108)
8) Muddy (east)	(14050004)
9) Vermillion	(14040109)

Simply stated, the above proposed order reflects the author's opinion assuming that watershed plans are initiated by the State. This is not the case. In fact, the WDO does not initiate or solicit projects. Projects come forth based on the efforts of sponsors.

8.6.2 Municipal and Domestic

Municipal Master Plan

Of the 14 municipal water providers, a review of records indicates that water master plans are either non-existent or more than 10 years old for the following: Bridger

Valley Joint Powers Water Board, LaBarge, Marbelton, Superior, and Wamsutter. If true, these entities should consider making requests to WWDC to fund updated plans.

Water Rights

Municipal water systems that use surface water should work to identify what early-priority agricultural water rights might be available for leasing, which was described in the strategies section of this chapter. These entities include the Green River Rock Springs Joint Powers Board, Baggs, Bridger Valley Joint Powers Water Board, Dixon, Granger, Kemmerer-Diamondville Joint Powers Water Board, LaBarge, and Pinedale. Assuming water quality needs are met, owners of water wells might also be considered for leasing of water rights. Perhaps the municipal water providers can execute first right of refusal agreements with likely agricultural interests, at very modest cost. Certainly this proactive work would position the water provider better than a reactionary approach to a curtailment. It is suggested that the state entertain the idea of funding the process of identification of these agricultural water right holders within the context of an updated municipal water master plan.

8.6.3 Industrial

Fontenelle Reservoir

Industrial interests may firm up their water supply situation by purchasing contracts to use Fontenelle water. An additional specific recommendation for achieving this is provided below under the action list for state government.

Agricultural Water Rights Leasing

As with municipal providers, industrial water users should carefully consider the benefits and costs associated with making advanced arrangements for temporary agricultural water right leases. See Section 8.6.2.

8.6.4 Recreation and Environmental

Riparian Areas

The benefits of riparian areas to the Green River Basin watershed are not easily quantified, but widely understood as having value. Riparian areas provide opportunities for water quality enhancement, stabilize stream flows, and provide many conditions needed to sustain beneficial ecological functions. This sentiment was consistently voiced at BAG meetings during the course of this study. The state might consider how to specifically quantify the benefits of riparian areas, in addition to quantifying benefits water brings to Wyoming's broader society and ecology.

8.6.5 Basinwide (State Agency)

State Engineer's Office

The SEO should continue to execute the recommendations presented in the Colorado River Compact Administration Project (Purcell, 2005), specifically:

- Prepare current and searchable water right tabulations.
- Update estimates of irrigation consumptive use.
- Obtain annual reports of water use from municipalities and industries.
- Measure and report on the annual exports out of the Basin.
- Collect annual records for reservoir storage, including amount stored, spilled, evaporated, released for use, and carried over.

The Colorado River Compact Administration Program (2008)

This SEO program is well thought out and broad in content. From the recommendations presented in the Colorado River Compact Administration Program: Consumptive Use Determination Plan (2008), the state should continue to fund and execute:

- 5 recommendations directed at climate and hydrology.
- 4 specific recommendations directed at measurement of diversions and determination of consumptive use. The importance of collecting good quality data cannot be overstated as a fundamental recommendation for future planning.
- 1 recommendation directed at water rights attribution.
- 2 recommendations related to reservoir operations and water storage.
- 1 recommendation for providing outside experts in the field of geohydrology.
- 4 recommendations related to administration and decision support tools.

Green River Basin Plan

It is suggested that this plan be re-examined in 2015 via an internal review by WDO staff. If changes are significant at that time, funding and planning for the next update should be performed by 2020. If major changes in water supply or water use have not occurred by that time, WWDC should shift focus towards watershed plans rather than updating basin-wide plans.

Irrigation Shortages

The scope of work in the next Green River Basin Plan or watershed plan or other efforts administered by the SEO should strive to more accurately quantify agricultural shortages.

Green River Basin plans to date have focused on estimating water available to new development or expansion of existing projects and providing a tool for testing effects of new development on the downstream basin. They have not focused on estimating the shortages, or difference between an ideal supply and the amount of water actually supplied to irrigators. The basin plans show how much water is used under the constraints of a limited supply and timing, location, and quantity of water left after the current level of use is exercised, no matter if the amount was adequate or not. The piece not quantified is the amount, timing, and location of the difference between an ideal supply for the acreage currently under irrigation and the existing supply. If this difference could be better estimated, then planners and engineers can evaluate how water could be made available to irrigators through storage or by moving water from one place to another to reduce the shortages.

The state must continue to collect records of diversion practices and quantities and to digitize historical data to facilitate its use in water accounting models. The state must also implement the climate data collection program recently invested in - both for the purposes of improving estimates of ideal supply as well as historical consumptive use, and then look at the difference between those quantities. This data collection effort would further the state’s investment in a Decision Support System (DSS) project for the Basin.

Marketing

The state might consider preparing a marketing plan for the water allocated to Wyoming by compact and stored in Fontenelle Reservoir. The plan should have all the elements of a sound marketing plan and be prepared by experts. The water marketing effort could be coordinated by the Wyoming Business Council (WBC) as a part of an overall effort to attract new businesses and industries to Wyoming. The WDO would be the logical technical support group for the marketing effort.

WBC’s publication, a newsletter entitled “Wyoming Business Images“, presents material on wind energy potential, coal gasification, and other natural resource subjects. The newsletter is directed at people doing or contemplating doing business in Wyoming and would be a logical place to present information on the availability of water resources in the Basin.

Instream Flows

The water availability analysis (Chapter 7) reflects the application of instream flow water rights. During BAG meeting No.4, a BAG member expressed concern that instream flow rights would impact the viability of other water projects by making less water available for consumptive uses.

A more detailed evaluation and description of how instream flows might limit water storage projects should be contemplated. If possible, WDO should identify, through cooperation with WG&F, WDEQ and others, the specific reaches of streams that have the most promise for being managed as instream flow segments. Next, an analysis of water rights and water supply through a time series simulation should be performed to see how reservoir yields would be reduced by the imposition of instream flow requirements in various drainages.

Glaciers

The base flow associated with glaciers should be monitored and trends should be noted (BAG meeting No. 8).

Oil Shale

The oil shale issue and its potential impact on the water supply and water use opportunities should be studied by state-funded water planning (BAG meeting No. 3 and No. 6).

Prescriptive Versus Descriptive Planning

Continuous critiquing in the basin planning process and evaluation of how to make the basin plans more useful would be beneficial. The descriptive nature and focus of basin plans is useful, but the scope of work needs clarification and focus. Before planning commences, a clear description of the planning purpose, goals and expected benefits needs to be developed. This recommendation was suggested by a BAG member at BAG meeting No. 6.

Specific Gaging Need

There are 16,000 irrigated acres below the last stream gage in the Little Snake River and above the Colorado state line. The amount of return flows leaving the state are unknown, but need to be assessed. This data would assist with estimating actual depletions. A gage location which would provide this information was identified and a new gage requested by a BAG member during BAG meeting No. 6. Other locations where new gages might be installed to provide key data for water administration or for planning purposes should be identified.

Information

Develop case study information based on successful water development projects and make it available to others contemplating water storage or other development projects. It would be useful to prepare a document that outlines the steps, contact agencies, permits, costs, etc., that went into the High Savery Reservoir storage project. The case study should include sample purpose and need statements.

Simulation modeling

It is recommended that the state develop an extended time period simulation model of the Basin which can simulate dry conditions with a particular focus on Fontenelle Reservoir and compact implications. The benefit of the reservoir for meeting a “call” in any one year seems intuitively obvious given the present hydrologic patterns and demands. The firm yield of the reservoir during extended extreme drought should be quantified. This type of information would possibly assist with the marketing of the water as suggested by a BAG representative during the Stakeholder Survey. This modeling advancement would benefit from the expansion of data collection efforts described elsewhere in this recommendations section.

Groundwater Determination - Wyoming State Geological Survey

The information and data collected and interpreted in the Green River Basin Available Groundwater Determination Report (WSGS, 2008) is an extensive and valuable addition to the water planning process. The summary recommendation presented in that report is directed at preparing accurate inventories of groundwater production and use. The WWDC, in cooperation with the WSGS, might consider translating this recommendation into a specific description of what additional production and use data is needed, and why. If the State Engineer’s Office is not compiling this information, then a new project to do so should be considered.

Water Storage Opportunities Near Warren Bridge

The State of Wyoming and other agencies have studied water storage opportunities at many locations in the Green River Basin. A compilation of those studies has been prepared by the Dam and Reservoir Section at WDO. The subject of water storage and possibilities for hydroelectric power generation near Warren Bridge (Kendall sites) surfaces from time to time, and was most recently mentioned during the BAG process of this current plan. In 2007, WDO prepared a “white paper” presenting a summary of the agency’s best available information and opinion regarding feasibility of water storage at this location. According to that paper, projects at the Kendall sites would require extensive conveyance systems to deliver the stored water on the west side of the Upper Green River Basin, would have significant environmental permitting challenges, would impact permitted instream flow water rights and would be very expensive. Based on 2007 reconnaissance level estimates, Upper Kendall Reservoir costs include $149,000,000 for construction of the dam and diversion structure, $67,500,000 for canal construction and $170,000,000 for tunnel construction, for a total of $386,500,000. The Lower Kendall Reservoir costs include $45,500,000 for construction of the dam, $67,500,000 for canal construction and $134,000,000 for tunnel construction, for a total of $247,000,000. The paper essentially concludes that due to high costs, a project at this location should not be pursued with state funding, and that more cost-effective opportunities should be sought elsewhere. Given current conditions that conclusion is still valid.

Watershed Plans

Watershed plans for the Green River Basin should be completed at a pace of about one per year prior to the next complete update of the Green River Basin Plan. This may actually necessitate that two or more plans are prepared concurrently, by WDO staff or consultants. The future basin plan update may take on an entirely new character, as it is likely to be an assemblage of data from several watershed plans (BAG Meeting No. 5). The watershed planning projects need the support and input of local stakeholders.

Recommendations from the Augmentation Technical Memorandum

- Continue to monitor the flow augmentation studies and efforts of others, particularly in the Lower Colorado Basin. With time, water demand and the economics of augmentation may demonstrate that enhancing flows in river basins has a favorable cost-benefit ratio. Since Wyoming contains the mountainous headwaters of the Green River, the opportunities and economies for flow augmentation may differ from those found in other locations.

- Wyoming is well underway on evaluating cloud seeding as one technology to augment mountain snowpack. Both physical and statistical methods will be used to quantify any water supply increases. Based on the findings of the pilot study, the State of Wyoming will need to determine whether cloud seeding is a cost-effective long term strategy for augmenting flows in the respective basins and whether the program should be funded operationally.

- Since the current study was initiated in 2007, there has been a BAG discussion regarding the effects of the pine beetle on water supplies generated from forested land. A study is being performed at the University of Wyoming that addresses this issue (Impact of Bark Beetle Outbreaks on Forest Water Yield in Southern Wyoming, Ewers, Pendall, Williams, & Barnard). The results of this and other studies should be brought to the attention of Basin residents via a public outreach effort.

Recommendations from the Watershed Planning Technical Memorandum

- Watershed plans should reflect and follow the progression of resource elements used to describe the watershed.

- Watershed plans should provide a watershed management and rehabilitation plan including water storage, irrigation and upland water development opportunities and considerations. The study should review permitting and environmental considerations as well as project financing options, cost estimates and the ability of stakeholders to pay for project implementation.

- Recommendations should be offered as to specific opportunities for irrigation system rehabilitation, upland water development and surface water storage. Potential projects should be located with some conceptual design offered.

Recommendations from the Institutional Constraints Technical Memorandum

- Project proponents should clearly define the purpose of their project.
- Project needs should be defensible.
- Consider all reasonable alternatives and provide reasons for eliminating those that are not feasible. Prior to concluding that a reservoir or storage impoundment is required to meet water supply needs, be sure to fully evaluate other alternatives, including:

    - Aquifer storage
    - Groundwater
    - Non-jurisdictional impoundments
    - Less environmentally damaging alternatives
    - Multiple projects that achieve the same objective
    - Conservation / reuse
    - Individual alternatives or combinations

Recommendations from the Water Quality Technical Memorandum

- In areas where mineral development is prevalent, such as the Pinedale Field area, and where a water quality concern exists, ongoing data collection and evaluation would provide a scientific basis to determine to what extent, if any, the mineral development and the oil and gas industry disrupt or contaminate water sources.

- Develop more effective ways to disseminate water quality information and educate the public efficiently and effectively (i.e. newspaper announcements of public meetings, published literature centrally posted or delivered by mail, etc., more use of the Internet , particularly social networking applications like Facebook, Twitter, etc.).

- Continue preparation of the Green River Basin Plan as the foundation and framework guidance document needed to better plan and manage the water, ultimately improving water quality by understanding and correcting local water quality challenges.

- Fund additional storage as a way to improve water quality.

- Upgrade infrastructure, irrigation systems and irrigation practices to improve water quality by increasing efficiency through improved irrigation management techniques. Improved management techniques often reduce the amount of chemicals applied to the land that eventually reach nearby waterways.

Recommendations from the Water Conservation Technical Memorandum

- Support local efforts and initiatives toward water conservation, particularly as irrigation districts consider conveyance improvements which may be beyond their means financially but of benefit to the Basin as a whole.

- Make conservation an opportunity that is evaluated in Wyoming Water Development Commission municipal master plans and watershed planning studies.

- Monitor the conservation studies and efforts of others, particularly in the Lower Colorado River Basin.

- Widen public education and outreach programs. In some cases, local conservation efforts could avoid or delay the need for capital projects.

Recommendations from the Climate Technical Memorandum

- The state should remain financially and technically committed to maintenance of the five Automated Weather Data Network (AWDN) climate stations recently established in the Basin. These stations were installed to support the Colorado River Compact Administration Program and are a significant step toward addressing the most obvious need in the Basin, which is for high quality instrumentation to allow observation of wind, solar radiation, humidity, and soil moisture. These are critical to developing realistic estimates of crop consumptive use and are integrated with an effort to bring new technologies to that task. In addition to their use in consumptive use estimation, these stations can support a variety of applications such as drought monitoring, renewable resources development, irrigation scheduling, and crop protection.

- The state should continue to participate in the National Integrated Drought Information System (NIDIS) through the State Climatologist's Office, and in particular, contribute to the Upper Colorado River Basin (UCRB) subgroup's efforts to develop a basin-focused drought monitor. As soil moisture data becomes available via the new AWDN stations, that information could be incorporated into the drought status reporting.

- The state should monitor progress and outcome of the NIDIS gaps assessment report, as well as the U.S. Climate Reference Network (USCRN) program density study, and pursue establishment of a USCRN station in the Basin. In high-relief areas like the Green River Basin, correlation between reference stations outside the Basin and other stations within the Basin are not expected to be strong. Establishment of a local high-quality station will help with all of the climate-related analysis that is currently done. The primary objective of USCRN, however, is to help understand long-term changes in climate, and the network is to have a 50 to 100 year life span. The station could eventually be instrumental in downscaling global climate models, which are currently on a scale that does not differentiate between conditions at Lander and conditions at Pinedale, for instance. One criterion for USCRN site selection is proximity and correlation with HCN stations; that requirement suggests a USCRN station near Pinedale.

Conjunctive Use

Specific recommendations to conjunctively manage groundwater and surface water supplies cannot be made without defining or describing the water supply/water quality problem that needs to be addressed. However, it may be possible to identify specific areas in the Basin where this approach may be more promising than others. Akin to a reservoir siting exercise where certain specific attributes are better (e.g. valley cross section geometry), a conjunctive use project also has site considerations that are more favorable at some locations than others (e.g. good geology for storing water and surface water supply to store). A map of the Basin should be produced identifying the ten best places to look at the conjunctive use concept in more detail.

Data Needs

The Availability work in Chapter 7 can be improved with more and better data. The following suggestions were provided by AECOM. AECOM was a subcontractor to WWC Engineering and responsible for determination of water availability in Chapter 7.

- The Little Snake River at Dixon has space in some recent Hydrographer's Report, but no data. There is some question as to whether the station is in place. The filling equations are adequate for winter months but appear to underestimate summer months.

- Throughout most of modeling period, there are only Henrys Fork data at Manila and no gage data at all from 1994 through 2001. This means that hydrology is almost completely estimated from data for late 1940's through about 1962. Seven gages have records for the period 1949 through 1954, 6 gages 1955 through 1962, 4 gages 1963 through 1971, 1 or 0 gages 1972 through 2007; more gages would make estimates of water availability in this area more accurate.

- In the Eden Project area the entire Big Sandy tributary was left out of the Green River model because the existing gage records didn't make sense, and significant pieces of the picture were missing entirely. Diversions off river to Big Sandy and Eden Reservoirs, reservoir contents, deliveries from the reservoir, and return flows via tailwater drainages would all help resolve the water availability more accurately in this area. That whole system should be instrumented, as least from the perspective of being able to be modeled.

- Abundant diversion data (Blacks Fork, Little Snake River, and maybe the Big and Middle Piney Creeks) should be digitized and reduced to monthly volumes. This data also must have start and end dates. There is also very little new diversion data in New Fork (District 7).

- The ongoing DSS study should consider performing a refined gaging station analysis to identify where and what types of gages would be most useful to meeting the current planning goals of the WDO and water administration goals of SEO. The area of analysis should focus on the west side of the Basin, especially those areas that appear to have promise for water storage projects.

8.7 REFERENCES

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9.0 PROJECT FUNDING

9.1 INTRODUCTION

Previous chapters of this report quantify water resources available for development and use, identify present and future water needs in the Green River Basin and explore future water development opportunities that could be pursued to assure that water is available to meet these present and future needs. In Chapter 8, several strategies for water development and management improvement were identified, including several specific projects. This chapter addresses various options that project sponsors might pursue to fund these water development and management improvement projects.

9.2 FUNDING OF WATER DEVELOPMENT PROJECTS

Water development projects are funded from federal, state, and private sources through grants, loans, private capital or a combination of these. Most of the large water development projects in the western U.S. have been federally funded; two examples of federally funded projects in the Basin are Fontenelle and Flaming Gorge Reservoirs. These reservoirs provide water for irrigation and power generation and have water available for sale for other uses, including municipal and industrial water.

The following sections explain some of the more common funding options that are available to water developers.

9.2.1 Federal Programs

Federal funding for water development projects is becoming increasingly difficult to secure for a number of political and economic reasons. Nevertheless, programs exist within federal agencies for smaller and environmentally focused projects. These types of projects might include habitat development, wetlands, or water quality improvements.

U.S. Department of Agriculture Rural Development Programs

The U.S. Department of Agriculture (USDA) has its state offices in Casper. The state through the Water Development Program has partnered with USDA Rural Development to jointly fund development of small community water supply systems throughout the state. The USDA Rural Development Program administers several grant and loan programs for rural water projects, including:

- Water and waste disposal direct and guaranteed loans for water and waste disposal systems in rural areas and small towns.
- Water and waste disposal grants covering up to 75 percent of the costs of eligible rural water and waste disposal projects.

Additional information regarding the USDA and its programs in Wyoming is available at http://www.rurdev.usda.gov/wy.

Natural Resources Conservation Service

The USDA Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), administers a wide variety of programs that provide funding for water-related projects, including but not limited to the:

- **Wildlife Habitat Incentives Program (WHIP)**: to improve wildlife and fish habitat on private lands.
- **Wetlands Reserve Program:** to protect, restore, and enhance wetlands on private lands.
- **Watershed Program:** to protect and restore watershed from damage caused by erosion and flooding and to conserve and develop water resources on a watershed basis.

Information regarding the NRCS and the various funding and assistance programs that the agency administers is available at http://www.nrcs.usda.gov/programs.

Environmental Quality Incentive Program

This program can provide funding to improve irrigation infrastructure, and land management practices to improve irrigation efficiency and effectiveness.

Western Native Trout Initiative (WNTI)

The mission of WNTI is to serve as a key catalyst for the implementation of conservation or management actions, through partnerships and cooperative efforts that result in improved species status, improved aquatic habitats, and improved recreational opportunities for native trout anglers.

U.S. Fish and Wildlife Service, National Fish Passage Program (NFPP)

This program is designed to restore native fish and other aquatic species. Projects include improving water quality where discharges fragment habitat, and installing grade control structures and screening diversions.

9.2.2 State Programs

The State of Wyoming also has several programs to help fund water resource projects.

Wyoming Water Development Commission (WWDC)

The WWDC, consisting of a 10-member board and professional staff, administers state funding of water development programs. The WWDC administers:

- **New Development Program (Account 1)**: focuses on development of unused and/or unappropriated water.
- **Rehabilitation Program (Account 2)**: focuses on improving existing water systems.
- **New Dam and Reservoir Program (Account 3)**: focuses on developing storage reservoirs to capture excess streamflows so they can be put to beneficial use during late summer when water is short.

Water resource planning programs, of which this Green River Basin Plan is a component, uses funding from all three of these accounts as deemed appropriate by the staff, approved by the Commission, and appropriated by the legislature

Projects are initiated by submittal of an application from a project sponsor. Applications for new projects are due by August 15 of each year and must include a $1,000 filing fee. The WWDC provides funding for a variety of water projects based on following prioritized categories:

- Multipurpose programs
- Water storage projects
- New water supply projects
- New supply (conveyance) system projects
- Hydropower projects
- Purchase of existing storage projects
- Watershed improvement projects
- Recreation projects
- Drinking Water State Revolving Fund projects

WWDC provides a detailed description of application procedures, eligibility criteria, and related information for use by entities wishing to apply for WWDC water project funding. Detailed information regarding WWDC funding of Wyoming Water Development Program projects may be found at http://wwdc.state.wy.us/opcrit.

Wyoming Department of Environmental Quality (WDEQ)

Several types of funding programs are available from the WDEQ, including:

- **205j Funds**: named for Section 205j of the federal Clean Water Act, to establish water quality monitoring programs when existing water quality data are inadequate to assess local water quality conditions. Information is available at http://deq.state.wy.us/wqd/watershed.
- **319 Funds**: named for Section 319 of the federal Clean Water Act, to implement new non-point source pollution water quality improvement projects or to evaluate the effectiveness of ongoing projects. Information is available at http://deq.state.wy.us/wqd/watershed.
- **State Revolving Funds for Drinking Water and Clean Water Projects**: The Drinking Water State Revolving Fund is for drinking water systems, including source, treatment plant, storage tank, and transmission and distribution line projects. The Clean Water State Revolving Fund is for sanitary sewer treatment and collection, storm water control, landfill water pollution control, and other water pollution control projects. Information regarding the funds is available at http://deq.state.wy.us/wqd/www/srf/index.asp.
- **Abandoned Mine Land Program (AML)**: carries out projects to eliminate safety hazards and repair environmental damage from past mining activities, as well as assisting communities impacted by mining. Impact assistance can include development of public facilities. Information regarding AML's funding program is available at http://deq.state.wy.us/aml.

State Lands and Investment Board

The State Lands and Investment Board (SLIB) administers loan and grant programs that can be used for project development and rehabilitation, including:

- **Mineral Royalty Grant Program**: to alleviate an emergency situation that poses a direct and immediate threat to health, safety, or welfare; to comply with a federal or state mandate; or to provide an essential public service.
- **Joint Powers Act Loan Program**: to provide loans for planning, construction, acquisition, improvement, emergency repair, acquisition of land, refinancing of existing debt, and operation of revenue-generating public facilities.
- **Impact Mitigation Grants and County Block Grants for Capital Projects:**, to provide grants for capital projects under provisions of Chapter 24 Emergency Rules and Regulations State Loan and Investment Board. Funding of these projects is based on county-wide consensus lists and funding availability for the benefit of the citizens of the state. Information regarding this program is available at http://slfweb.state.wy.us/grants/revgrantupdate.aspx.

The SLIB provides the financial oversight and management of the State Revolving Fund programs. These State Revolving Fund programs are jointly managed by WWDC, WDEQ, and SLIB. More information on SLIB funding programs is available at http://slf-web.state.wy.us/grants.aspx.

Wyoming Wildlife Natural Resources Trust Fund

The Wyoming Wildlife Natural Resources Trust Fund Board administers a trust fund to preserve and restore wildlife habitat and open spaces. The income from the trust fund is used to supply grants to nonprofit and government groups for specific projects. Information regarding the fund is available at http://gf.state.wy.us.